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ONE MAN ELECTROCHEMICAL AIR REVITALIZATION SYSTEM

FINAL REPORT

by

JOHN C. HUDDLESTON AND DR. JOHN R. AYLWARD

PREPARED UNDER CONTRACT NAS 9-13679

by

HAMILTON STANDARD

DIVISION OF UNITED TECHNOLOGIES CORPORATION

WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

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ABSTRACT

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CONTRACT NAS 9-13679

MAY 1975

This report describes the work performed under NASA contract NAS 9-13679, in the design, fabrication and testing of an integrated Water Vapor Electrolysis unit and a Hydrogen Depolarized Carbon Dioxide Concentrator unit, sized to provide the air revitalization necessary for one man.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

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ABBREVIATIONS AND SYMBOLS

A amp(s)	ampere(s)
AR	as required
Asf	Amperes per square foot
aux.	auxiliary
avg.	average
BET	method for measuring surface area by gas adsorption
°C	degrees Celsius (centigrade)
cc	cubic centimeter
cfm	cubic feet per minute
cm^2	centimeter squared
CO_2	Carbon Dioxide
Cs_2CO_3	Cesium Carbonate
$CsHCO_3$	Cesium Bicarbonate
dc	direct current
DP	dew point
DPDT	Double Pole Double Through
DS-16	Code name for HDC Cathode (fabricated by Hamilton Standard)
E/C ARS	Electrochemical Air Revitalization System
F	Fraction of reservoir volume unutilized
°F	degrees Fahrenheit
Ft	foot

ABBREVIATIONS AND SYMBOLS (CONT'D)

G.F.E.	Government Furnished Equipment
g	grams
H_2	hydrogen
HCO_3^-	Bicarbonate Ion
HDC	Hydrogen Depolarized Carbon Dioxide Concentrator
Hsg	housing
Hg	mercury
hr	hour
H_2O	water
H_2S	Hydrogen Sulfide
H_2SO_4	Sulfuric Acid
I	current
i	current density
in.	inches
IR	voltage drop
k	kilo
K	kelvin temperature
kg	kilogram
kPa	kilo Pascals
lb	pound
max.	maximum

ABBREVIATIONS AND SYMBOLS (CONT'D)

mA/cm^2	milliAmpere per square centimeter
mg/cm^3	milligrams per cubic centimeter
min	minute
ml	milliliter
mm	millimeter
mmHg	millimeters mercury
mPa	milli-Pascals
Mv	free electrolyte volume in the matrix
mV	millivolt
N_2	nitrogen
Nom.	nominal
O_2	oxygen
P	pressure
Pa	Pascals (unit of pressure equal to 1 Newton/meter^2)
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge
P_{H_2O}	Partial Pressure of Water Vapor
P_{O_2}	Partial Pressure of Oxygen
P_{CO_2}	Partial Pressure of Carbon Dioxide
P/N	Part Number
PPF	Code name for HDC Anode (Mfg. by P&W)

ABBREVIATIONS AND SYMBOLS (CONT'D)

ppm	Part Per Million
P&WA	Pratt & Whitney Aircraft, Division of United Technologies Corporation
R	Resistance (ohms)
Rec.	Receive
Rv	Reservoir volume
R.H.	Relative Humidity
S	Specific Volume Ratio of Electrolyte
scc	standard cubic centimeter
SCFM	Standard Cubic Feet per Minute
sec	second
SEC	Code Name for Experimental Electrode
SEM	Scanning Electron Miscroscope
S/N	Serial Number
SSP	Space Station Prototype
T	Temperature
T_{in}	Inlet Temperature
TMA	Tetramethylammonium
TMAC	Tetramethylammonium Carbonate
UAC*	United Aircraft Corporation
Vac	Volts alternating current
Vdc	Volts direct current

*The name of United Aircraft Corporation was changed to United Technologies Corporation on May 1, 1975.

ABBREVIATIONS AND SYMBOLS (CONCLUDED)

WVE	Water Vapor Electrolysis
wt.	weight
wt. %	weight percent

$\sim$	Approximate
$\approx$	Approximately Equals
Δ	Delta
$=$	Equals
$<$	Less Than
μ	Micro (10^{-6})
%	Percent

FOREWORD

This report was prepared by Hamilton Standard, Division of the United Technologies Corporation, for the National Aeronautics and Space Administration's Johnson Space Center, in accordance with contract NAS 9-13679. This report describes the work accomplished during the period of November 1973 through June 1975, in performing the One Man Electrochemical Air Revitalization System (One Man E/C ARS) program. This effort consisted of detailed system design, cell pair and system fabrication and testing, and delivery of the unit to the NASA.

Personnel responsible for the conduct of this program were Mr. F. H. Greenwood, Program Manager; Mr. J. C. Huddleston, Program Engineer; Dr. J. R. Aylward, Technical Consultant, from Hamilton Standard; and Mr. A. F. Behrend and Mr. Nick Lance, Technical Monitors, and Mr. R. J. Gillen, overall program supervisor, for the NASA Johnson Space Center.

DEFINITIONS

Cell	Electrochemical cell consisting of an anode, matrix with electrolyte, and cathode.
Cell Pair	Two cell packages with back to back hydrogen electrodes which share a common hydrogen chamber, housing and reservoir assemblies.
Concentration Over-Voltage	Voltage loss due to electrolyte concentration differences between electrodes.
Dry Out	The condition of the cell, due to the loss of water, when the volume of the electrolyte is insufficient to fill the matrix completely.
Flooding	The condition of the cell when the electrolyte has absorbed an amount of water which results in an electrolyte volume exceeding the capacity of the cell matrix and electrodes.
H_2 Crossover	Occurs at dry out of the matrix and allows hydrogen and oxygen to pass through the matrix.
IR Check	Measurement of IR drop by current interruption.
IR Drop	Voltage loss due to pure ohmic resistance.
Potential Sweeps	A programmed potential change--usually a triangular wave.
Reservoir	A porous material which absorbs the excess electrolyte during cell flooding and returns it to the matrix during drying conditions.
Steady State Operation	The operating condition when the cell voltage and current do not change significantly with time.
Tafel Slope	The slope of the Tafel curve.

SUMMARY

The objectives of this program to design, fabricate and test an integrated Water Vapor Electrolysis (WVE)/Hydrogen Depolarized CO_2 Concentrator (HDC) system sized for one man support over a wide range of inlet air conditions, were accomplished. The One Man Electrochemical Air Revitalization System (One Man E/C ARS), illustrated in figure 1, was designed to integrate four WVE cell pairs and four HDC cell pairs into one package, with a second package designed to control and monitor the operation of the system. The test program proved that an integrated WVE/HDC system is a practical and feasible concept for a portable air revitalization "window unit" that is applicable for spacecraft or other life support requirements.

In addition, the test results obtained from one hundred and ten days of testing the One Man E/C ARS provided parametric data on the system's performance at three inlet air partial pressure of carbon dioxide (PCO_2) levels, six HDC operating currents and one WVE current level. This data verified that the One Man E/C ARS provides the necessary oxygen (0.998 kg/day), carbon dioxide removal (0.998 kg/day) and partial humidity control to support one man (without exceeding a cabin P_{CO_2} level of 3.0 mmHg and while maintaining a 20 percent O_2 level), when operated at a WVE current of 50 amperes and an HDC current of 18 amperes.

A study to determine means for utilizing the HDC power output revealed a concept of operating the WVE and HDC units electrically in series. This concept when fully executed would have the WVE and HDC cell pairs sized to obtain 100 percent utilization of the HDC power and minimum WVE power usage for a totally integrated WVE/HDC system based on operating the HDC cell pairs at the peak CO_2 removal efficiency, and the WVE cell pairs at optimum current density. However, the HDC power to be utilized represents only about two percent of the total 340 watts power required for the One Man E/C ARS.

An evaluation to determine the physical properties of tetramethylammonium bicarbonate and hydroxide was made. These data, when combined with the tetramethylammonium carbonate (TMAC) data obtained under a previous NASA contract (NAS 9-12920), provide the necessary electrolyte information for designing an HDC cell using TMAC.

Items delivered to the NASA included the two One Man E/C ARS packages, a system Familiarization and Operations Manual, and a complete set of microfilmed detail drawings. The various aspects of reliability, safety and maintenance were stressed throughout the program's design, fabrication and testing.

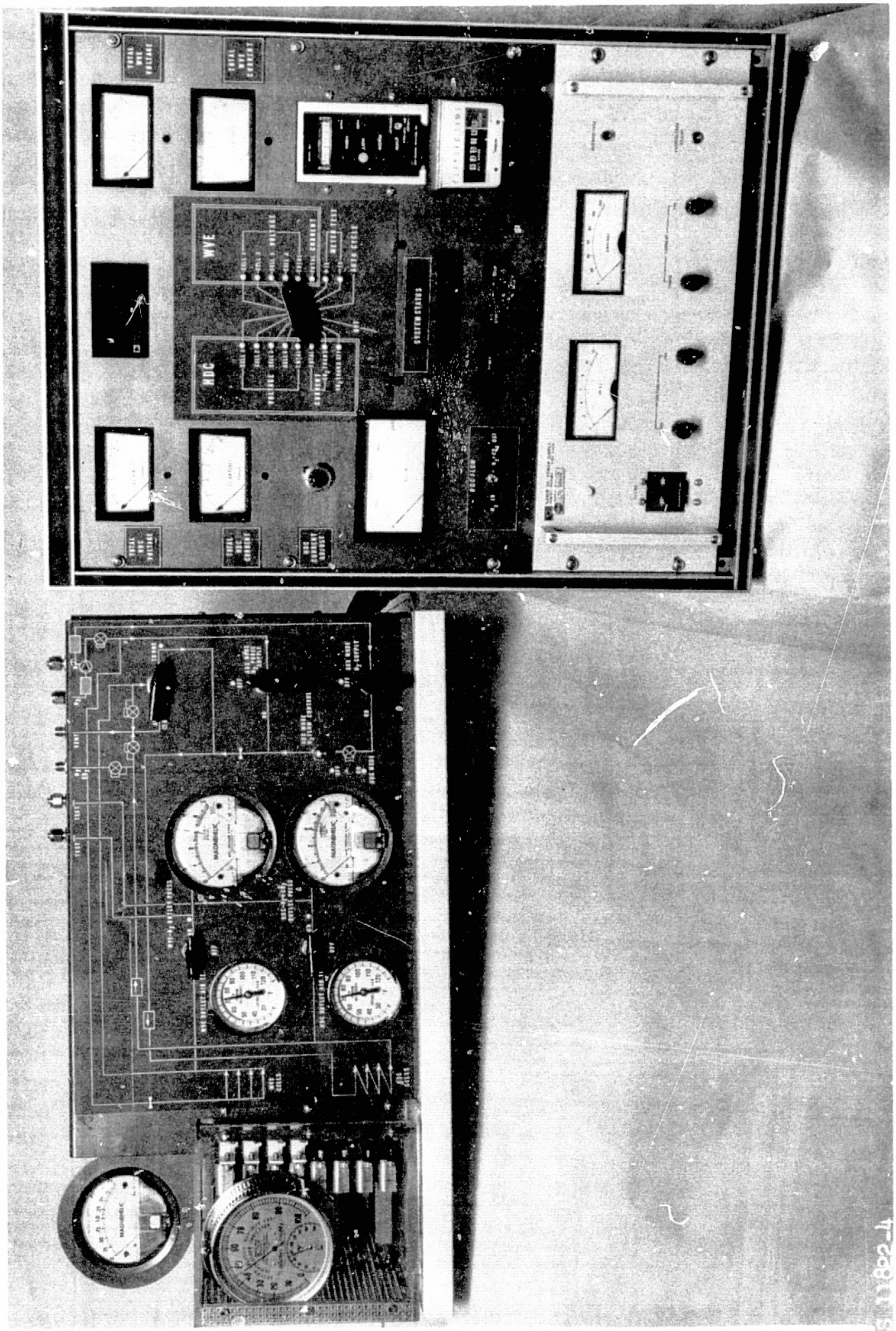


FIGURE 1 ONE MAN ELECTROCHEMICAL AIR REVITALIZATION SYSTEM

In addition to successfully meeting the above requirements for the One Man E/C ARS, the following were verified:

- Minimal WVE voltage degradation of 8 μ volts/hr.
- Average WVE cell voltage of 1.7 volts at a current density of 53.8 mA/cm^2 (50 Asf).
- A short term reversible voltage decay associated with the HDC. Automatic anode reactivation for the HDC cells allows them to operate continuously at a current of 18 amperes.
- A long term HDC voltage decay rate of 30 μ volts/hr at 18 amperes which is well within the design goal decay rate limit of 50 μ volts/hr, maximum.

The accomplishments obtained on this program met or exceeded the requirements of the contract's statement of work summarized in Table I.

"Calculations and data pertaining to this program, were made in U.S. customary units and then converted to S1 units".

TABLE I CONTRACT REQUIREMENTS VERSUS PROGRAM ACCOMPLISHMENTS

Contract Requirements	Program Accomplishments
Evaluate the integrated WVE/HDC concept as a portable Air Revitalization System.	Testing of the One Man E/C ARS proved this concept is practical and feasible as a "window type" ARS.
System will be limited to A-C power, and N_2 gas for auxiliary supplies.	A-C power of 110 and 220 volts plus N_2 purge gas are the only auxiliary needs of the One Man E/C ARS.
The system shall be:	
Reliable	The 110 day failure-free test duration proves the system's reliability.
Easily maintained	The cell pair concept and system packaging provides an easily maintained unit.
Simple to operate	The present One Man E/C ARS has only two controls, HDC current and WVE current. Future systems can be made with only one current controller by operating the WVE and HDC's in series.
Provisions for performance monitoring at HDC and WVE subsystem and cell pair level will be made.	All requested parameters are monitored plus the additional parameters of: CO_2 removal efficiency, elapsed time, combustible gas level and an auto-cycle which automatically displays all the monitored parameters in sequence.
System will have controls for normal operation and automtic shutdown in case of system failure.	Controls for the normal operation plus three auxiliary modes of operation are provided, including automatic shutdown for each mode in case of system or test facility malfunction.
The system will have operational tolerance over 35 to 90 percent relative humidity range.	System tests were conducted mostly (95 percent) at 70 percent relative humidity, however, inlet air conditions did include a range of 20 to 80 percent relative humidity during various facility malfunctions
Performance of the system will sustain one man for O_2; CO_2 removal and partial humidity control. Provide 0.834 kg O_2/day Remove 0.998 kg CO_2/day at P_{CO_2} of 3 mmHg.	System tests verified: O_2 Production = 1.423 kg O_2/day -0.512 kg O_2/day HDC consumption 0.911 kg O_2/day to cabin CO_2 Removal = 1.02 kg CO_2/day at P_{CO_2} of 3 mmHg H_2O Consumed = 1.610 kg H_2O/day -0.580 kg H_2O/day produced by HDC 1.030 kg H_2O/day removed from cabin
The HDC power will be utilized.	A concept for 100 percent utilization of the HDC power was derived (operating WVE/HDC's electrically in series) but not incorporated in the One Man E/C ARS because of the cost. Present system uses approximately 20 percent of the HDC power.
Contract change to determine the physical properties of TMA was made.	The physical properties of TMA electrolyte were determined. A separate report was submitted.
To complete the defined program within the negotiated funds.	The program was successfully completed within the funding provided by the contract.

INTRODUCTION

This program was conducted in accordance with NASA contract NAS 9-13679 to design, fabricate and test a One Man Electrochemical Air Revitalization System.

NASA contract NAS 9-13679 is a follow-on to NASA contract NAS 9-12920 which provided:

- Detailed characteristics of the HDC electrolyte.
- New HDC electrodes (DS-16-0 & PPF).
- Verification of improved HDC CO_2 removal rate and decreased long term power degradation.
- Verification that the present cell pair design (common to both HDC and WVE) is capable of withstanding launch vibrations levels.

This contract (NAS 9-13679) continued the development of the integrated WVE/HDC concept for O_2 generation, CO_2 removal and supplemental humidity control of a spacecraft, by providing for the design, fabrication and extensive testing of an engineering prototype One Man E/C ARS.

This program was revised during the course of the program to 1) determine the properties of tetramethylammonium bicarbonate and hydroxide, and 2) allow an investigation of the change in HDC performance at the cell pair level.

CONCLUSIONS

The results of this program for the design, fabrication and testing of a One Man Electrochemical Air Revitalization System lead to the following conclusions:

- Testing of the One Man E/C ARS proved that the integrated WVE/HDC system is a practical and feasible concept for a portable air revitalization "window unit" that is applicable for spacecraft or other life support requirements.
- The One Man E/C ARS, when operated at a WVE current of 50 amperes and a HDC current of 18 amperes, will provide the cabin with the additional oxygen (0.998 kg/day) and CO_2 removal (0.998 kg/day which prevents the cabin air P_{CO_2} from exceeding 3 mmHg) to sustain one man.
- One hundred percent utilization of the HDC power output can be obtained by combining the WVE and HDC cells electrically in series, rather than in separate circuits as in this One Man E/C ARS. However, this HDC power output is only 7.2 watts, representing only 2.1 percent of the total power used by the One Man E/C ARS.
- To obtain maximum savings of the power used by the One Man E/C ARS, the HDC's should be operated at the current level where peak CO_2 removal efficiency occurs. For the TMAC electrolyte HDC cell pairs developed during this program, this optimum current level is 14 amperes for cabin P_{CO_2} levels of 2.5 to 3.0 mmHg.
- Changing the HDC matrix material from fuel cell asbestos (chrysotile) to asbestos-neoprene (blue asbestos) reduced the long term voltage decay of approximately 200 μ volts/hr to less than 30 μ volts/hr, versus the design objective of 50 μ volts/hr maximum.
- The average voltage decay rate of the WVE cells was less than 8 μ volts/hr.
- The change in the CO_2 removal capability of the HDC's as a function of time was insignificant, and less than the instrumentation accuracy.
- There is a reversible short term voltage decay associated with the HDC's. However, the voltage can be restored to its original value by reactivation of the anode by a short (10 second) nitrogen gas purge. This short term voltage delay is due to the formation of "reduced CO_2" on the anode surface which is oxidized off during the N_2 purge.

- Periodic reactivation of the HDC anode enables continuous operation of these cells at 18 amperes with a very minor system penalty of 7.5 grams nitrogen/day (0.0165 lb/day).
- The electrical resistance of the TMA electrolyte is 3.3 times greater than that of the cesium carbonate electrolyte.

RECOMMENDATIONS

Based on the various study conclusions, cell pair and One Man E/C ARS test results of this program, the following recommendations are made:

- Operating the WVE and HDC units electrically in series will provide 100 percent utilization of the HDC power output without complex controls or auxiliary equipment. This operational concept should be used in future integrated WVE/HDC systems.

- Sizing of future WVE and HDC cell pairs should not be restricted by the concept of hardware commonality between the HDC and WVE cell pairs, but should have the respective cell pairs sized for maximum CO_2 removal efficiency, HDC power utilization and total system power conservation.

DISCUSSION

The discussion of the results obtained from this program is separated into six sections. These sections correspond to the major areas of activity that were performed during the program and are titled:

- Design
- System Fabrication
- Test Program
- HDC Electrolyte Properties
- Preparation for Delivery
- Reliability/Quality Assurance/Safety Summary

DESIGN

The objective of the design task was to define and provide a detail design of a One Man E/C ARS to meet the system requirements as stated in the NAS 9-13679 contract Statement of Work. The discussion of the design section is, therefore, divided into three parts; system design requirements, system design, and detail design & component descriptions.

System Design Requirements

The following general design requirements, reference Table II, are pertinent to the One Man E/C ARS, which will provide the required oxygen, CO_2 removal and moisture removal (supplement to cabin heat exchanger removal) in the air revitalization for one man.

TABLE II DESIGN DATA/REQUIREMENTS

VEHICLE	Value	
System Operating Parameters		
Cabin total pressure, kPa (psia)	101	(14.7)
Cabin oxygen partial pressure, kPa (psia) (To be maintained by oxygen generator).	22	(3.2)
Cabin temperature, K (°F)	291.45 to 297.05	(65 to 75)
CO_2 partial pressure, Pa (mmHg)	333 to 400	(2.5 to 3.0)
Operational gravity, g's	0 to 1	
Dew Point, K (°F)	289.85 to 280.93	(62 to 46)
CREW		
Perspiration and respiration, kg H_2O/man/day (lb H_2O/man/day)		
Nominal	1.50	(3.31)
Minimum (18.3°C cabin temperature)	0.594	(1.31)
Maximum (23.9°C cabin temperature)	3.67	(8.09)
Metabolic Oxygen Consumption, kg O_2/man/day		
Nominal	0.834	(1 84)
Minimum	0.766	(1.69)
Maximum*	0.998	(2.20)
CO_2 Production, kg CO_2/man/day (lb CO /man/day)		
Nominal	1.0	(2.20)
Minimum	0.871	(1.92)
Maximum**	1.22	(2.68)

ONE MAN E/C ARS

The system should be portable and shall not require any auxiliary equipment other than power for operation. It should also be reliable, easily maintained and simple in operation.

The system shall have provisions for monitoring individual cell voltages and system voltages, pressures, temperatures, flow rates, and effluent H_2, CO_2 and/or O_2 gas, etc. The primary system parameters shall be displayed to confirm proper operation.

The system shall have controls which maintain WVE and HDC operation at constant current levels and provide automatic system shutdown in case of facility or system failure.

Cell Pair Hardware

To meet program costs, the WVE and HDC cell pair design is constrained to using the existing cell pair housings fabricated on previous NASA contracts.

System Operating Parameters (not included by Statement of Work)	Value	
N_2 purge gas, kPa (psia)	122	(3)
H_2 vent for system kPa (psia)	101.0	(14.7)
DC power for WVE's -- power supply provided by NASA JSC.		

System Packaging

The system should consist of two packages; a cell pair package and an instrumentation/control package.

System Operation

The One Man E/C ARS should be designed to operate as an integrated WVE/HDC system as well as being capable of independent WVE and HDC operation. Provisions will also be made to permit operation at various HDC and WVE current levels and various air flow-rates.

*Will occur at high relative humidity conditions.
**Will last only eight hours maximum during a 24-hour period.

System Design

The One Man E/C ARS was designed to meet the design requirements listed in Table II, in addition to providing maximum flexibility with regard to test parameters, system operating modes, system controls, power utilization, performance monitoring, safety features, and ease of system maintenance. The One Man E/C ARS consists of two packages, one containing the cell pairs, valving and blower, and the other package containing all the electrical controls and monitoring instrumentation. This design concept provides a small cell pair package, which can easily be installed in a test chamber for providing the desired inlet air conditions, and a control package that can be set up outside the test chamber for ease of monitoring the system performance and setting the system controls.

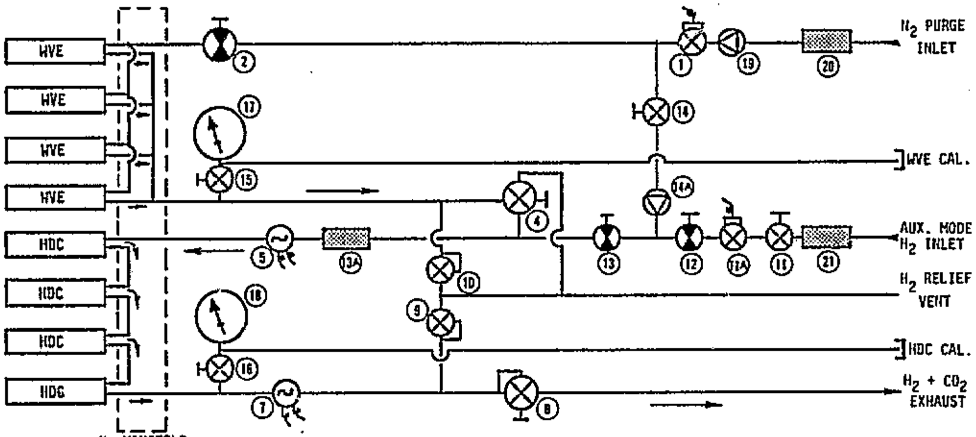
Cell Pair Package

The cell pair package, illustration figure 2, contains four WVE cell pairs, four HDC cell pairs, a cell pair rack/manifold housing, external valving, instrumentation and an air blower.

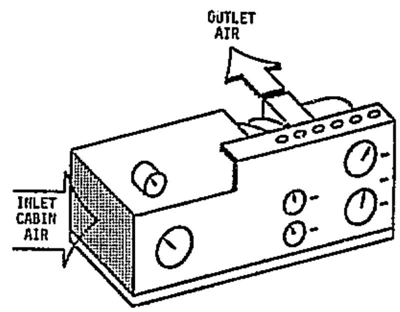
The eight cell pairs (4 HDC and 4 WVE) are held in a horizontal position in a "plexiglass" housing by means of side slots into which the sides of the cell pairs slide. This housing also incorporates a hydrogen manifold which connects the hydrogen inlet and outlets of the cell pairs (cell pair H_2 probe) into the correct flow path. Attached to the rear of this housing is a blower which provides the air flow.

Air is drawn through each cell pair, arranged in parallel air flow paths, by a blower located on the downstream side of the cell pairs. This air provides the water vapor for WVE electrolysis and the CO_2 for HDC removal. It also provides cooling of the cell pairs and an exhaust for the liberated oxygen from the WVE to return to the cabin atmosphere. Variation in the rate of air flow is provided by changing orifice plates on the blower exhaust port. The WVE is powered by a controlled dc current source for electrolyzing the water removed from the air. The H_2 produced by the WVE is manifolded from each cell pair in a parallel manner to a common outlet port. As shown on the schematic of figure 2 the external plumbing of this H_2 gas prior to entering the HDC cell pairs includes the following components.

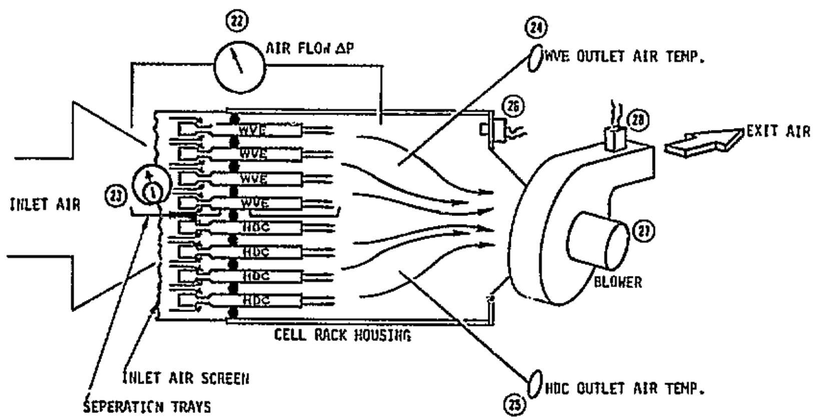
- A pressure gauge to monitor the WVE backpressure. This gauge has an inlet shut-off valve to isolate it from the system for periodic calibration, using a test port.



H_2, $H_2 + CO_2$ & N_2 SCHEMATIC



CELL PAIR PACKAGE



AIR FLOW SCHEMATIC

Item No.	Component Description	Vendor
1	Solenoid Valve, Normally Open	Skinner
2	Metoring Valve	Nupro
3	HVE (4) Cell Pairs	Hamilton Standard
4	3-Way Ball Valve	Whity
5	Flow Sensor (H_2)	Tylan
6	HDC (4) Cell Pairs	Hamilton Standard
7	Flow Sensor (H_2+CO_2)	Tylan
8	Pressure Regulator 20.6 mPa (3psi)	Tescom
9	Relief Valve (HDC) 34.48 mPa (5psi)	Circle Seal
10	Relief Valve (WVE) 34.48 mPa (5psi)	Circle Seal
11*	On-Off Ball Valve Aux. H_2	Whity
11A	Solenoid Valve Normally Closed	Skinner
12*	Metering Valve Aux. H_2	Nupro
13	Metering Valve Aux. N_2	Nupro
13A	LiOH Filter	Hamilton Standard
14*	On-Off Ball Valve Aux. H_2	Whity
14A	Check Valve	Nupro
15*	On-Off Ball Valve WVE Press. Gauge	Whity
16*	On-Off Ball Valve HDC Press. Gauge	Whity
17*	Pressure Gauge, Magnehelic, WVE 0-5 psig	Dwyer
18*	Pressure Gauge, Magnehelic, HDC 0-5 psig	Dwyer
19	Check Valve	Nupro
20	Filter H_2 Inlet	Nupro
21	Filter Aux. H_2 Inlet	Dwyer
22*	ΔP Gauge, Magnehelic Air Flow 90-2 in. H_2O	Dywer
23*	Combined Relative Humidity/Temp. Gauge Inlet Air	Cole Parmer
24*	Temp. Gauge, WVE Air Outlet (25-125 F)	Cole Parmer
25*	Temp. Gauge, HDC Air Outlet (25-125 F)	Cole Parmer
26	Combustible Gas Sensor	General Monitors
27	Blower	Rotron
28	Air Flow Sensor Switch	Rotron

* Panel Mounted Component

FIGURE 2 CELL PAIR PACKAGE

- A 20.68 kPa (3 psi) relief valve to protect the WVE from H_2 overpressure which would exceed the WVE matrix bubble point. The exhaust of this relief valve is connected to a H_2 vent system (NASA facility interface).

- A three-way ball valve for directing the WVE produced H_2 to the HDC or to the H_2 vent for the auxiliary mode.

- A LiOH filter, which will absorb any possible trace of WVE electrolyte carryover in the H_2 flow. This was added after the initial system testing as a preventive measure to insure no possible way of the sulfuric acid electrolyte entering the HDC cells.

- A mass flow sensor to measure the H_2 flow just prior to its entry into the HDC hydrogen manifold. The actual meter readout of this flow is located on the instrumentation/control panel.

The H_2 manifold connects the HDC cell pairs in a series flow path where a portion of the H_2 is consumed by the HDC and CO_2 that was removed from the air stream is exhausted into the H_2 flow. The H_2 + CO_2 exits the HDC manifold and the external plumbing includes the following components:

- A mass flow sensor, which measures this flow, and its meter readout which is located on the instrumentation/control package panel.

- A pressure gauge to monitor the HDC backpressure. This gauge has an inlet shut-off valve to isolate it from the system for periodic calibration.

- A 20.68 kPa (3 psi) relief valve to protect the HDC from overpressure.

- A 6.89 kPa (1 psi) backpressure regulator to maintain a positive H_2 system pressure to insure against the possibility of air entering the H_2 system. This regulator exhausts the H_2 + CO_2 to the NASA interface.

The auxiliary mode of the cell pair package allows the WVE and the HDC to be operated independently. That is accomplished by switching the H_2 from the WVE to the vent using the three-way ball valve, and supplying the HDC with facility hydrogen through the following valving:

- A H_2 supply port to interface with NASA H_2 facility gas is provided. This port also provides a protective filter for the downstream metering valves of the system.

- A manual on-off ball valve, a normally closed solenoid valve for automatic shutdown, and a fine metering valve to regulate the inflow of H_2 to the HDC cell pairs. This auxiliary H_2 gas enters the main H_2 system just upstream of the mass flow sensor on the inlet to the HDC.

Other auxiliary modes of operating the WVE only or the HDC only are provided also, by similar valve positioning. The actual sequencing of setting up the system to operate in its normal or auxiliary modes is defined in the systems Operation/Maintenance Manual.

Prior to the startup and upon shutdown of the One Man E/C ARS, a nitrogen purge is required. This purge gas, supplied by the NASA facility, enters the cell pair package through a filter and a check valve. This check valve prevents the possibility of H_2 flowing back into the N_2 supply system. The N_2 purge gas is automatically controlled by a normally open solenoid valve and a metering valve for the standard startup mode and all automatic or manual shutdowns. When the system is used in the auxiliary mode, the N_2 purge for the HDC is controlled by a ball valve and a separate metering valve.

The cell pair package contains the following instrumentation and safety devices:

- Two temperature dials that display the outlet air temperature of the WVE and HDC cell pairs.
- A relative humidity gauge that measures the inlet air relative humidity and temperature.
- A differential pressure gauge that measures the ΔP of the air flow across the cell pairs.
- An air flow sensor located on the exhaust of the blower, to sense low system air flow.
- A combustible gas detector sensor element located in the downstream air flow, to sense any excessive H_2 leakage.

The cell pair rack/manifold housing, the air blower and the display panel, to which all of the external plumbing and instrumentation is attached, are mounted on a unistrut support base. This base/frame allows ease of handling the package and a secure mounting base for the larger components of the package.

Cell Pair and Package Sizing.- The selection of the number of cell pairs,* air flow and overall system integration to meet the requirements of Table II, was based on test data and experience of previous WVE/HDC programs (NAS 9-11830 and NAS 9-12920). The following is a detailed analysis of the component sizing.

HDC Cell Pair.- Parametric testing on a small cell (1/24 standard cell pair area), with TMAC electrolyte over an air inlet relative humidity range of 33 percent to 89 percent at 294.25 K (70°F) showed no significant effect of relative humidity on CO_2 transfer efficiency. An air volume flow rate, equivalent to 4.72 liters/sec (10 cfm) or greater on the full size cell, had no effect on the CO_2 transfer efficiency at P_{CO_2} above 133 Pa (1.0 mmHg). At a CO_2 partial pressure of 33.3 Pa (0.25 mmHg) and an air flow rate of 4.72 liters/sec (10 cfm), the CO_2 mass transport limitations were significant. These were minimized at air flow rates equivalent to 11.3 liters/sec (24 cfm). Figure 3 shows the effect of current density on the CO_2 transfer efficiency at three different P_{CO_2} levels. There is a rapid drop off in efficiency with increasing current density but the absolute amount of CO_2 processed increases slightly (figure 4). At P_{CO_2} of 400 Pa (3 mmHg), experience has shown that there is a more rapid decrease in the amount of CO_2 processed when the current is reduced below 19.4 mA/cm^2 (18 Asf). For this reason 19.4 mA/cm^2 (18 Asf) was chosen as the nominal current density for the cell pair.

The CO_2 removal efficiency of the HDC cell pair using TMAC was 75 percent to 80 percent at P_{CO_2} of 400 Pa (3.0 mmHg). Allowing for a 10 percent safety factor (efficiency of 72 percent), the system is sized as follows:

- Nominal CO_2 production (design requirement) 1.0 kg CO_2/day/man.
- At 100 percent efficiency, CO_2 is removed at a rate 19.7 g CO_2/day/amp.
- $$(1.0 \text{ kg } CO_2\text{/day}) \frac{1}{19.7 \text{ g } CO_2\text{/day/amps}} = 51.0 \text{ amps @ 100 percent efficiency.}$$
- HDC at 19.4 mA/cm^2 (18 Asf) & 72 percent efficiency =

$$\frac{51 \text{ amps}}{18 \text{ amps/cell pair} \times 72\%} = 3.93 \text{ cell pairs}$$

The maximum CO_2 production rate of 1.22 kg CO_2/man/day (2.68 lb/CO_2/man/day) is a peak output which lasts for a maximum of eight hours. During this period the P_{CO_2} will rise slightly with a corresponding increase in the HDC current efficiency.

* The HDC and WVE cell pairs are identical in effective area of 929.0 cm^2 (1 sq. ft.) and are G.F.E. from previous NASA programs.

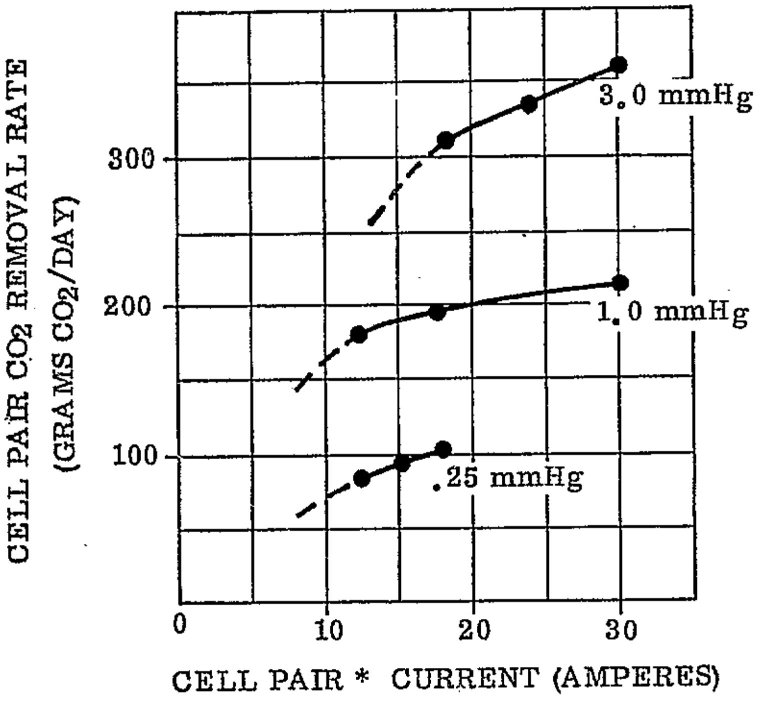


FIGURE 4 CO_2 REMOVAL RATE VS. CURRENT DENSITY AT VARIOUS INLET AIR P_{CO_2} LEVELS **

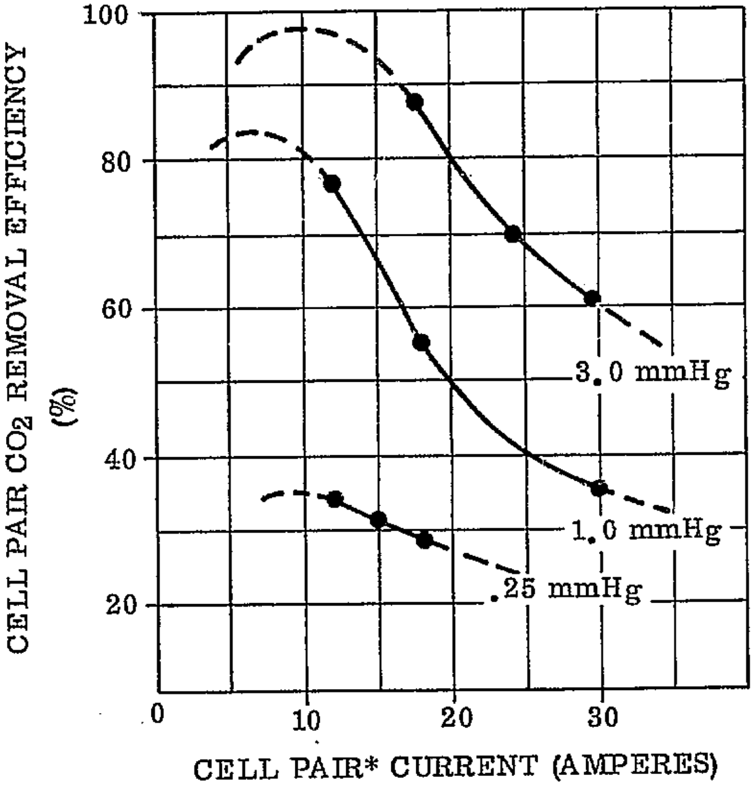


FIGURE 3 CO_2 REMOVAL EFFICIENCY VS. CURRENT DENSITY AT VARIOUS INLET AIR P_{CO_2} LEVELS **

* 929 CM^2 (1 SQ FT) CELL PAIR AREA

** Data obtained from Final Report NAS 9-12920 Report (CR-134159) "Analytical Cell Performance"

The required hydrogen flow to support the HDC would theoretically be:

4 cell pairs) x (18 amps/cell pair) x 0.895 g(H_2/day/amp) = 64.4 g H_2/day

Previous tests* show that the maximum HDC power occurs at a H_2 flow of 2.8 times stoichiometric or (2.5) (64.4 g H_2/day) = 180 g H_2/day which is provided by the WVE. The WVE's operating at 50 amperes (as determined below) and the HDC's at 18 amperes, provides a H_2 flow rate through the HDC's of 2.78 times stoichiometric (50/18 = 2.78).

WVE Cell Pair.- The design requirement is to maintain a constant oxygen partial pressure of 22.06 kPa (3.2 psia) in the cabin under varying ambient air humidities and a nominal crew consumption of 835 g/day (1.84 lbs/day). To maintain this P_{O_2} level, the WVE will be operated at constant current in order to provide sufficient oxygen to meet oxygen consumption.

One man consumption (nominal) = 835 g O_2/day

HDC oxygen consumption for 4 cell pairs @ 18 Asf = (4 cell pairs) x (18 amps/cell pair) x 7.13 g (O_2/day/amp) = 512 g O_2/day

Total oxygen consumption = 1347 g O_2/day

Total amperes required = (1347 g O_2/day) x $\left(\frac{1}{7.13 \text{ g lb } O_2\text{/day/amps}}\right)$ = 189 amperes

To produce O_2.

The dryest inlet air conditions are 35 percent relative humidity at 291.45 K (65°F). At this condition each WVE cell pair will operate at 50 amperes at 1.9 Vdc. Since 1.9 Vdc is the maximum continuous duty operating voltage for the WVE, it was calculated that the total number of WVE cell pairs for the system (based on 50 amperes per cell pair) required would be four.

(189 amperes) x $\frac{1}{50 \text{ amps/cell pair}}$ = 3.79 (WVE cell pairs)

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* Reference Final Report of NAS 9-12920 contract (SVSHER 6285) "HDC Hydrogen Flow Improvement", NASA Report CR-134159.

Under the wettest inlet air conditions of 90 percent relative humidity at 297.05 K (75°F) the WVE cell pair voltage will be 1.66 Vdc at a current of 50 amperes.

To meet the maximum oxygen consumption requirement, of 1.51 kg O_2/day (3.33 lb O_2/day) which occurs at a dew point of greater than 280.37 K (45°F) as calculated below, the WVE current would be 53.0 amperes.

HDC O_2 consumption for 4 cell pairs @ 18 amperes	= 0.512 kg O_2/day
One man consumption (maximum)	= 1.0 kg O_2/day
Total	1512 g O_2/day

$$(1512 \text{ g } O_2/\text{day}) \frac{1}{7.12 \text{ g } O_2/\text{day/amps}} \times \frac{1}{4 \text{ cell pairs}} = 53.0 \text{ amperes}$$

This current can easily be obtained at the slightly higher dew point conditions by operating at 1.8 volts.

In order to support the 50 amperes operation of the WVE cell pairs at the dryest inlet air conditions, a minimum of 3.30 liters/sec (7 cfm) at one atmosphere air flow through each cell pair is required. Since the HDC cell pairs will be operated at 4.72 liters/sec (10 cfm)/cell pair, (the HDC and WVE cells are in parallel), this requirement is met.

Cell Pair Reservoir Sizing.- Since the HDC matrix material was changed from fuel cell asbestos to a composite of neoprene asbestos and Tissuquartz, it was necessary to resize the reservoir to accommodate HDC cell pair operation over the relative humidity range of 35 to 90 percent. The three factors affecting reservoir sizing are the electrolyte volume in the cell matrix and electrodes, the fraction of free reservoir volume not utilized due to a finite electrolyte retention, and the ratio of electrolyte specific volumes at maximum and minimum relative humidities. All three factors should be minimized to limit the reservoir size. The HDC electrode separation should be at least 0.5 mm (0.020 inches)* to obtain good CO_2 transfer efficiencies, and the matrix void volume should be greater than approximately 40 percent to prevent excessive electrolyte resistance. The matrix void volume is determined by the nature of the matrix material and the compressive force, which should be between 170 kPa (10 psig) and 515 kPa (60 psig) to maintain good interfacial contact without excessive force on the cell housings.

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* Reference Final Report of NAS 9-12920 contract (SVHSER 6285) "Matrix Characteristics", NASA Report CR-134159.

Based on the above consideration, the HDC matrix composite chosen is (from anode to cathode) neoprene asbestos - Tissuquartz - neoprene asbestos. The total "solid" thickness of these materials is 0.24 mm (.0094 in.) At an electrode spacing of 0.5 mm (.02 in) this composite matrix void volume is about 52 percent and the required compressive force is 515 kPa (60 psig).

The reservoir volume R_V is given by

$$R_V = \frac{Mv\ (S-1)}{1 - SF}$$

where M_V is the free electrolyte volume in the matrix and electrodes. S is the electrolyte specific volume ratio (max/min), and F is the fraction of reservoir volume unutilized. For the selected matrix composite, M_V = 29.6 ml (1.81 in^3) and with TMAC electrolyte from 35 to 90 percent relative humidity the value for S is 4.0. Therefore,

$$R_V = \frac{88.8\ (ml)}{1 - 4F}$$

and R_V versus F is shown plotted in figure 5 where it can be seen that the reservoir volume increases rapidly for values of F above 0.2. It was found that an HDC cell pair with TMAC electrolyte and the composite matrix with a 285 ml (17.39 in^3) reservoir could be operated over a 90 percent to 40.6 percent volume of 450 ml (27.46 in^3) should be sufficient to accommodate* operation over the required relative humidity range of 90 to 35 percent.

The value of M_V for the WVE cell pair is 18.3 ml (1.12 in^3) based on a 0.25 mm (6.35 in) electrode separation and the other factors are the same as for the HDC cell pair so that a reservoir volume of 450 ml (27.46 in^3) is more than sufficient for the WVE cell pair.

Cell Pair Package Sizing.-The One Man E/C ARS is based on four WVE cell pairs and four HDC cell pairs, which are rack mounted in a plexiglass structure so that air will flow through the cell pairs in parallel. The parallel air flow, versus series air flow, was selected because it provides a more maintainable (easier cell pair removal) system, a better packaging arrangement, and no carryover of electrolyte from one subsystem to the other in case the unit is accidently subjected to very high (exceeding 90 percent) relative humidity. The design of the cell pair rack/manifold housing provides easy installation of the cell pairs by sliding them into their respective slots, inserting the hydrogen probe on the cell pair into the manifold socket of the cell pair rack housing, connecting the clip on to the electrical leads, and installing the air flow seals on the bottom isde of the cell pair housings.

*Reference Final Report of NAS 9-12920 contract (SVHSER 6283) "Electrolyte Properties". NASA Report CR-134159.

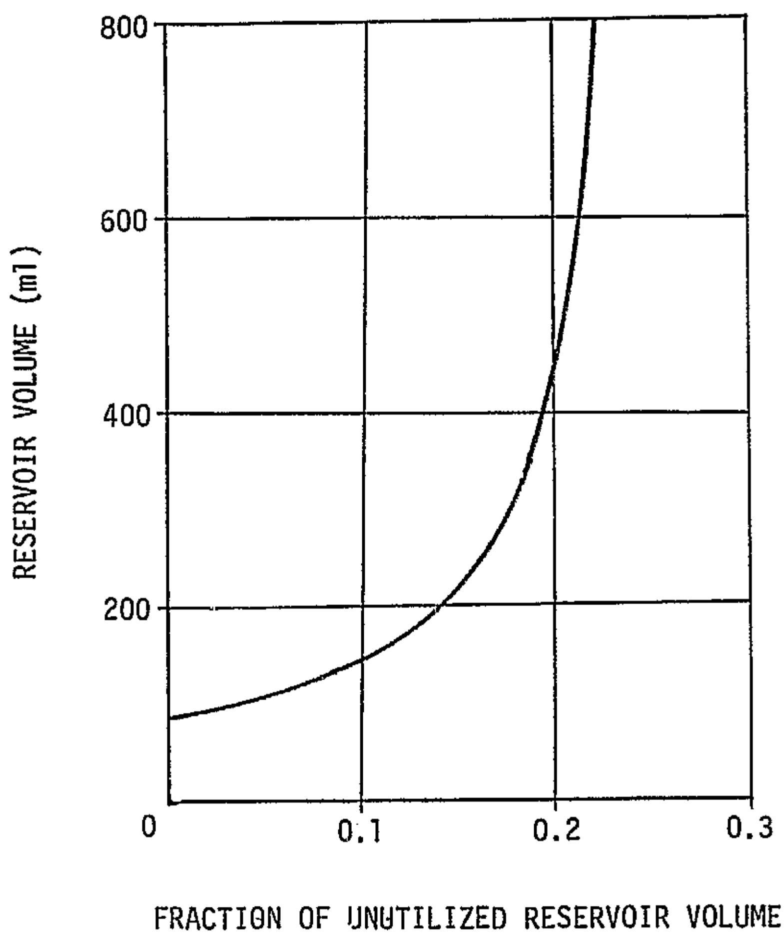


FIGURE 5 EFFECT OF RESERVOIR ELECTROLYTE RETENTION ON RESERVOIR VOLUME REQUIREMENTS

Since the WVE and HDC cell pairs require the same air flow at nominal conditions, the system is sized for 37.76 liters/sec (80 cfm) (8 cell pairs at 10 cfm) and a pressure drop of 100 Pa (0.4 inches) of water. This air flow is sufficient for operation down to 133 Pa (1.0 mmHg) P_{CO_2}. At lower P_{CO_2} levels the air flow is increased to 11.3 liters/sec (24 cfm) per cell pair for a total of 90.4 liters/sec (8 cell pairs) at a pressure drop of 249 Pa (1.0 in. of water), to prevent limitations in the HDC cells CO_2 transfer rate due to gas phase mass transport phenomena. A Rotron KS-508 Blower provides sufficient flow to meet these requirements (reference figure 6). The lower flow rate is maintained by an outlet orifice plate on the blower discharge that limits the system to 37.76 liters/sec (80 cfm). When the unit is operated at the low P_{CO_2} levels, not required for normal operation, this plate is removed allowing the blower to operate at its predicted performance.

The hydrogen produced by the WVE's is manifolded and fed to the HDC cell pairs in series arrangement. This is done to keep the porting simple, and insure hydrogen flow to all HDC cell pairs. The H_2 + CO_2 flow from the HDC will be discharged to NASA's facility; the flow then can be vented, or directed to a CO_2 analyzer either of which must not backpressure the system by more than 6.89 kPa (one psi). The interface definition of the cell pair package is provided in Table III and figure 7.

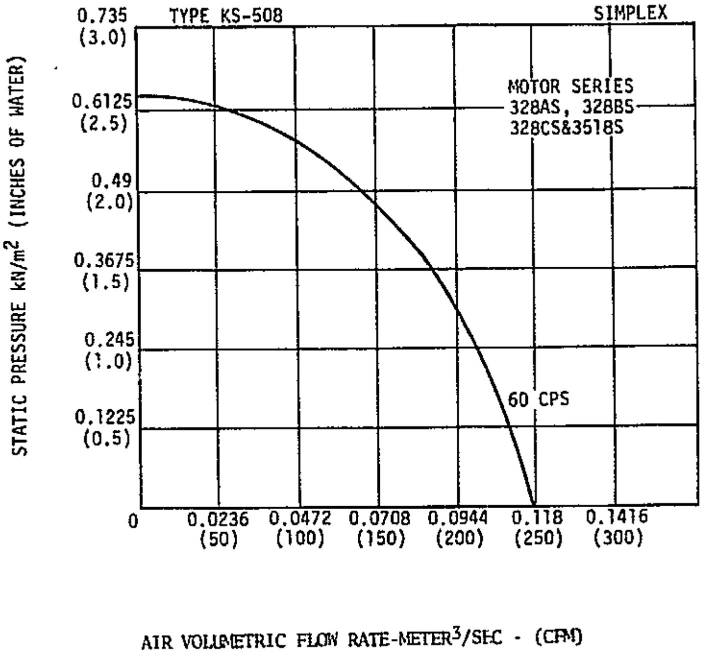


FIGURE 6 ROTRON BLOWER PERFORMANCE

TABLE III CELL PAIR PACKAGE INTERFACE REQUIREMENTS

Inlet & Exit Gas Media	Interface Requirement	
N_2 Purge Gas	34.47 kPa (5 psi) 2000 SCCM	Max Pressure Max Flow
Aux. Mode H_2	34.47 kPa (5 psi) 2000 SCCM	Max Pressure Max Flow
H_2 Relief Exit Gas	6.89 kPa (1 psi) 2000 SCCM	Max Vent Pressure Max Flow
$H_2 + CO_2$ Exit Gas	6.89 kPa (1 psi) 2000 SCCM	Max Vent Pressure Max Flow
WVE/HDC Pressure Gauge Calibration Gas	34.47 kPa (5 psi)	Max Pressure
Package Weight	18.14 Kg. (40 lbs)	

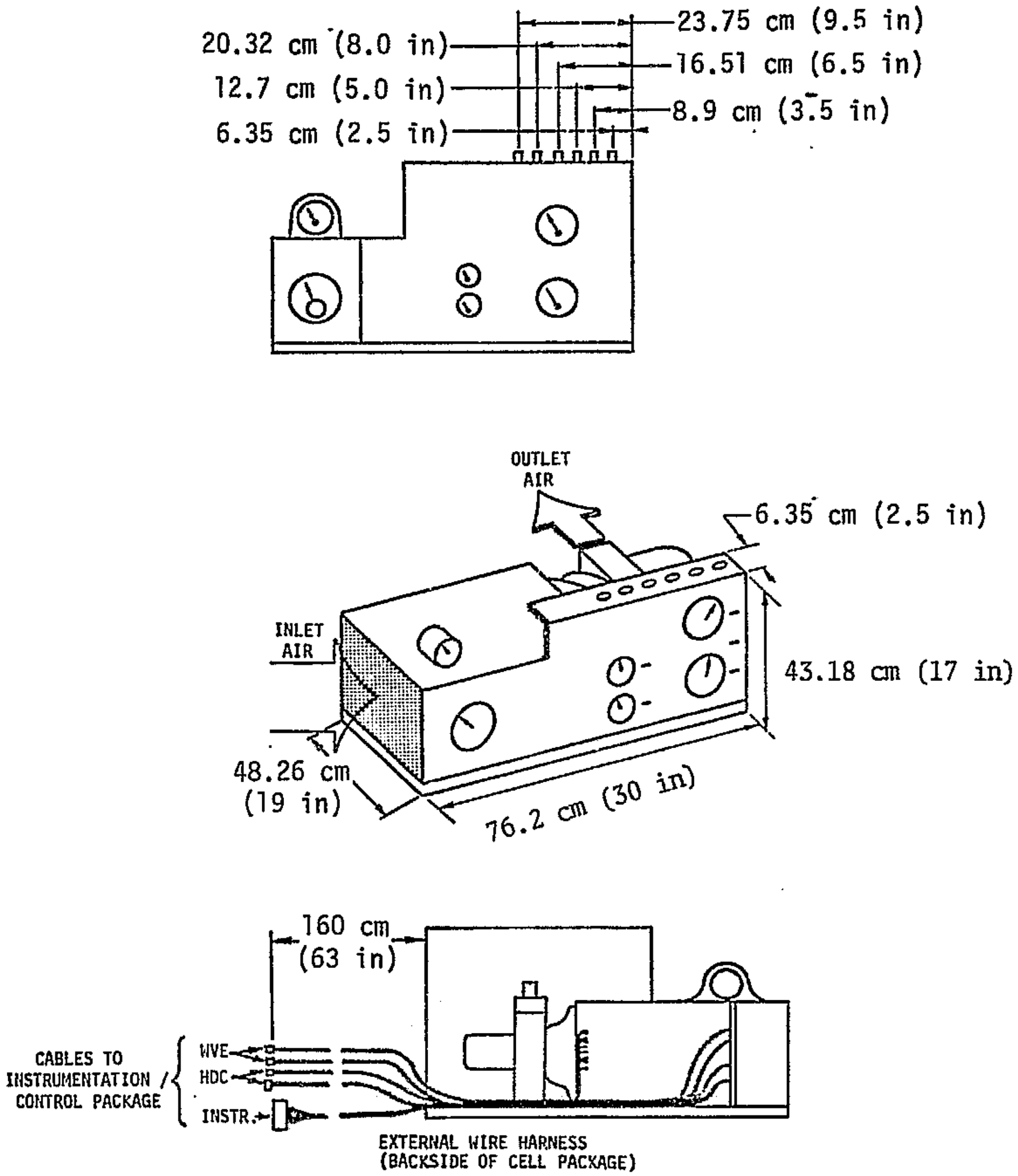


FIGURE 7 INTERFACE DEFINITION OF THE CELL PAIR PACKAGE

Instrumentation/Control Package

The Instrumentation/Control Package illustrated by figures 8 and 9 and by drawing SVSK 88485, provides four major functions, 1) system power, 2) malfunction isolation and detection, 3) current control, and 4) system performance monitoring. These four functions are discussed in this section. Descriptions of the various components of this package are provided in the detail design section.

System Power.- The electrical power to operate the system is 110 Vac and 220 Vac for the WVE power supply. The 110 Vac power is used in all the smaller dc power supply units and in most of the relay circuits of the system logic control.

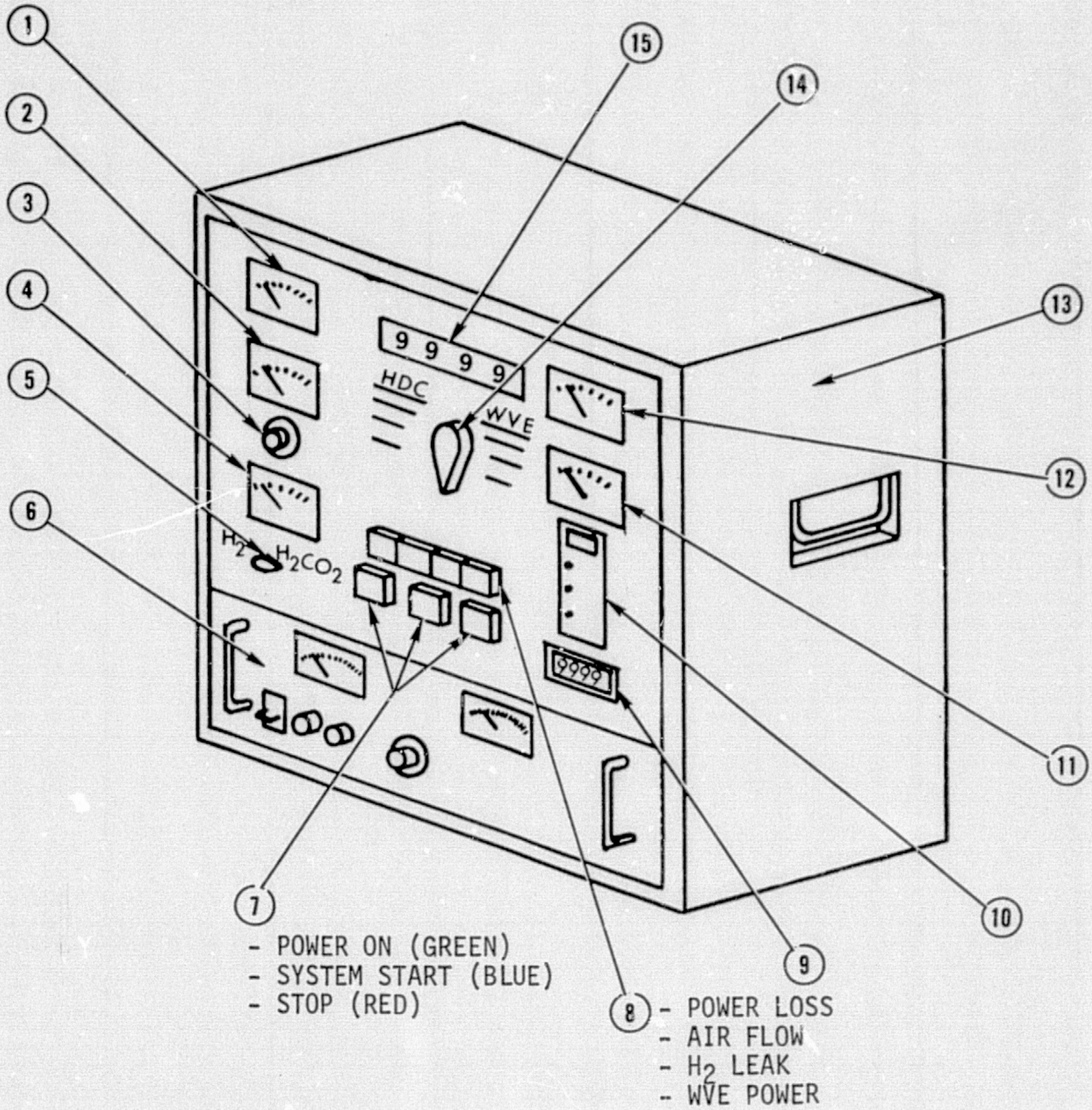
The system power requirements range from powering the WVE cell pairs to the lower power requirements necessary for instrumentation. The WVE power supply is supplied by NASA-JSC. This unit is a 100 amp/10 Vac Hewlett Packard power supply that supplies the WVE with the required power at constant current at the desired current density level.

The three smaller internal dc supply units are used for the instrumentation, CO_2 calculation circuit, and in the system logic. These units provide direct current at 6 amperes, 24 Vdc at 2.3 amperes and 15 Vac at 1.3 amperes.

Malfunction Isolation and Detection.- There are four main malfunctions that could occur in the facility or system that would damage the cell pairs or produce an unsafe mode of operation. These malfunctions are loss of facility 115 Vac power, reduction or total loss of air flow, H_2 leakage and loss of dc power to the WVE cell pairs. These malfunction parameters are continually monitored and the occurrence of any one will automatically shut down the One Man E/C ARS and actuate the appropriate malfunction indicator light.

The automatic system shutdown performs the following sequence of events.

- Actuates the N_2 purge solenoid for five minutes.
- Removes power from the WVE. A series of relays actuates the Hewlett Packard power supply's current regulation system to zero amperes.
- Shorts-out the WVE cell pairs. This prevents the formation of H_2S, and is done ten seconds after the shutdown sequence has been initiated.



ITEM NO.	COMPONENT DESCRIPTION	VENDOR
1	HDC TOTAL VOLTAGE	SIMPSON
2	HDC CURRENT	SIMPSON
3	HDC CURRENT ADJUST	BOURNS
4	H_2 AND H_2+CO_2 FLOW METER	TYLAN
5	SWITCH, SELECTOR FOR H_2 FLOW METER	MICROSWITCH
6	10 VDC - 100 AMP POWER SUPPLY	HEWLETT PACKARD *
7	SWITCHS - PUSH BUTTON W/INDICATOR LIGHT	MICROSWITCH
8	INDICATOR LIGHTS	MICROSWITCH
9	ELAPSED TIME METER	SIMPSON
10	COMBUSTIBLE GAS METER	GENERAL MONITORS
11	WVE CURRENT	SIMPSON
12	WVE TOTAL VOLTAGE	SIMPSON
13	CABINET	PREMIER
14	SWITCH-ROTARY-CELL CURRENT/VOLTAGE SELECTION	CENTRA LAB
15	DIGITAL METER	ANALOG DEVICE

* NASA - JSC SUPPLIED COMPONENT

FIGURE 8 ONE MAN E/C ARS INSTRUMENTATION/CONTROL PACKAGE

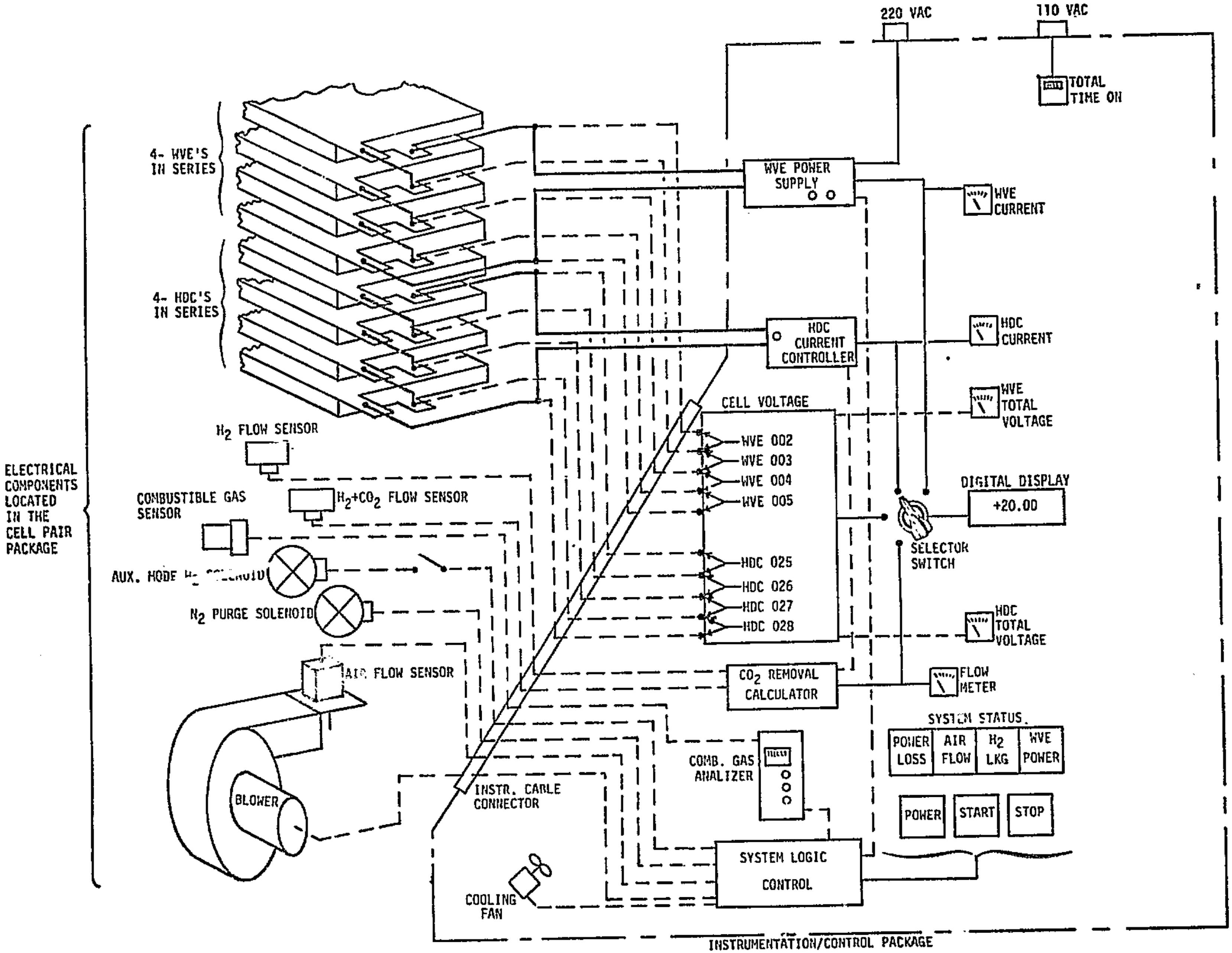


FIGURE 9 ONE-MAN E/C ARS ELECTRICAL SCHEMATIC SKETCH

- Actuates an interlock to prevent the restart of the system without a manual restart action. This is done through relays. On the system restart, a 10 second time delay to override the automatic shutdown mode is provided to allow sufficient time for the air flow through the cell pairs to build up.

Current Control.- The HDC operates at a constant but adjustable current level that is automatically controlled by the HDC current controller. This solid state current controller, reference figure 10, will automatically provide a constant cell current with changes in cell characteristics. The controlling device uses a PNP power transistor, which is driven by a solid state amplifier as part of a feedback loop. Current is sensed by a series shunt and compared to a set value. The proper input is provided to the controlling power transistor to drive the error to zero. A potentiometer is supplied to permit adjustment (setting) of the desired cell current (5 to 24 amperes). The current regulator requires the output power of the HDC and supplementary 15 volt Vdc power supply to power the solid state circuitry.

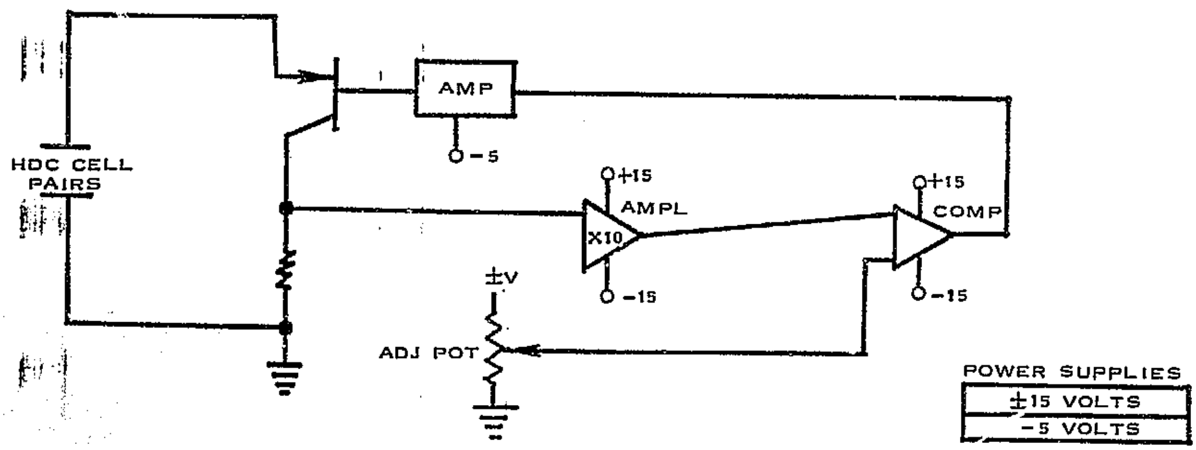


FIGURE 10 HDC CURRENT CONTROL SCHEMATIC

The second current control is part of the Hewlett Packard supply unit. This control maintains the WVE at a constant current level that is adjustable through the range of zero to 100 amperes. The power utilization section of this report discusses various ways to control the HDC and WVE current levels for future integrated systems.

System Performance Monitoring.- There are two levels of system performance monitoring provided, namely, total HDC and WVE current/voltage levels and individual cell pair voltage levels. The total cell pair current and voltage levels are displayed with dial meters which are visible at all times. The individual cell voltages and other system performance parameters are displayed on a digital meter, one parameter at a time. A manually operated, 18 position rotary switch or an automatic stepping relay device is used to select the various performance parameters that are displayed on the digital meter. These parameters are:

HDC - Cell No. 1 Voltage Cell No. 2 Voltage Cell No. 3 Voltage Cell No. 4 Voltage Stack Voltage	WVE - Cell No. 1 Voltage Cell No. 2 Voltage Cell No. 3 Voltage Cell No. 4 Voltage Stack Voltage
HDC Current	WVE Current
CO_2 Transfer Current*	Meter Test + 15 volts
CO_2 Efficiency**	Meter Test - 15 volts

When the manual rotary switch is placed in the "auto cycle" position, the stepping relay automatically sequences continually through the above parameters with a five second pause at each position.

*The CO_2 transfer current is the current required to remove the same amount of CO_2 which the HDC is removing but at 100 percent efficiency. This is calculated electronically by comparing the H_2 inflow to the H_2 + CO_2 outflow.

**CO_2 efficiency is obtained electronically by dividing the CO_2 transfer current signal by the actual HDC current signal.

Interface definition of the instrumentation/control package is shown in figure 11 and as listed below:

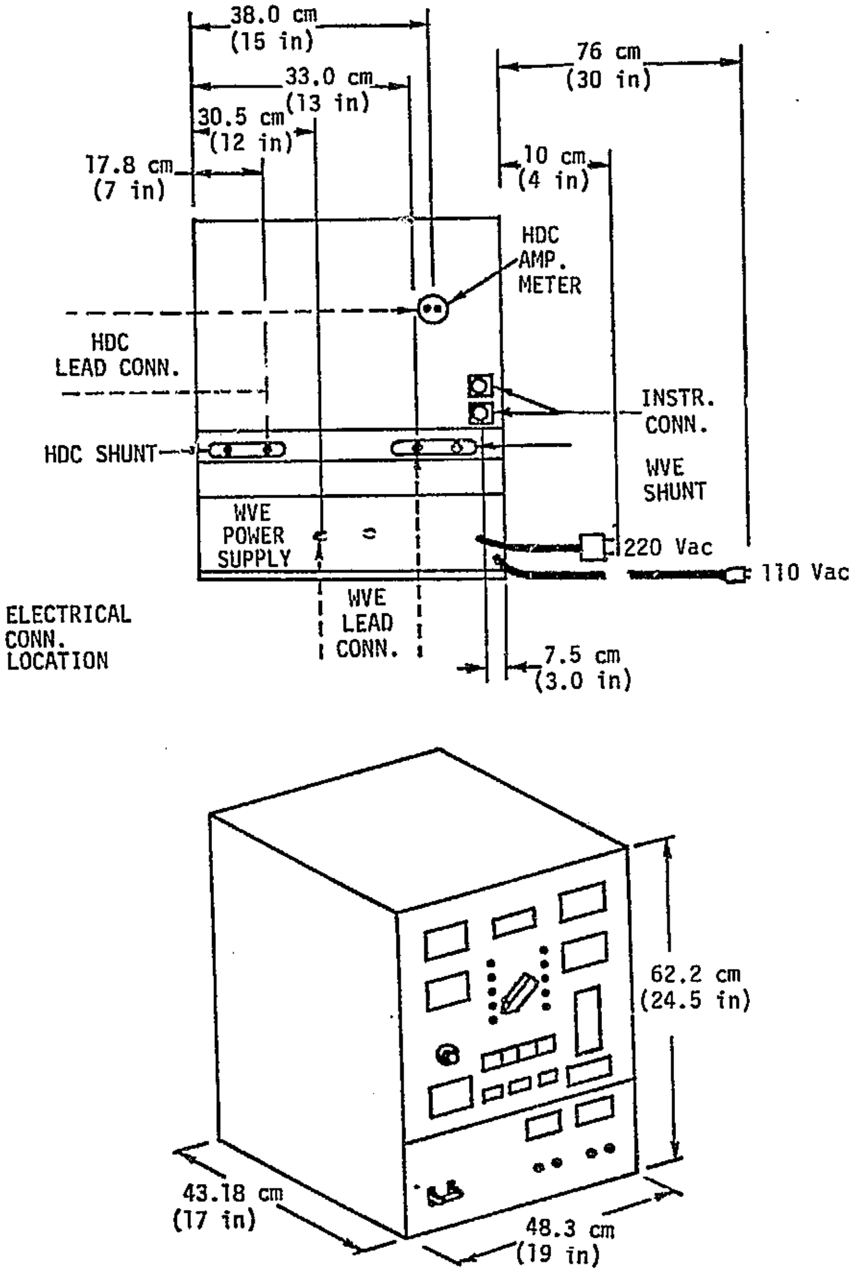


FIGURE 11 INTERFACE DEFINITION OF THE INSTRUMENTATION/CONTROL PACKAGE

Power Utilization Study

The study of methods to utilize the power produced by the HDC of the One Man E/C ARS revealed that the best utilization would be realized by placing the HDC's electrically in series with the WVE's; however, this method was not incorporated in this program because of additional costs, the possible jeopardy to the WVE performance and the program objectives would not be penalized if this series operation were not incorporated.

Study Restraints and Requirements.-

- Use cell pair hardware on hand (one square foot effective area) with minimum modifications.
- Maintain the design philosophy of minimum controls and simplicity of design.
- HDC Operation: - Constant current, peak CO_2 removal efficiency occurs at 18 amperes and power output varies with inlet air conditions and operating current. At nominal conditions the cell voltage would be approximately 0.2 volt at 18 amperes.
- WVE Operation: - Constant current, and input power requirements vary with inlet air conditions.

One way to utilize the HDC power and still control the HDC current is to place the HDC cells electrically in series with the WVE cells. In this concept the voltage of the constant current power supply required for WVE operation is reduced by the "stack" voltage produced by the HDC cells and would also eliminate the separate HDC current control.

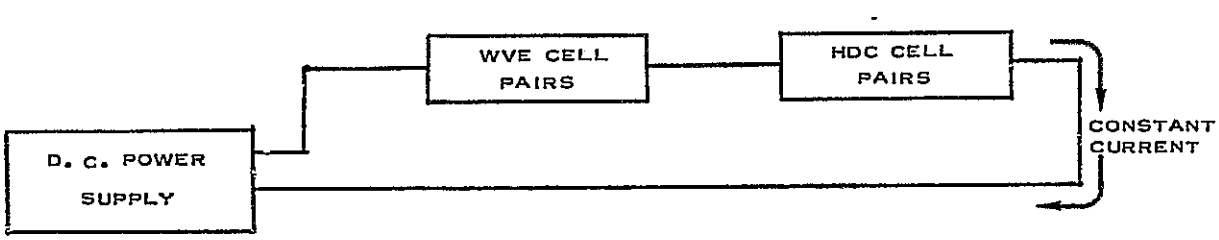


FIGURE 12 SERIES CONCEPT

Series Concept Advantages and Limitations.-

Advantages:

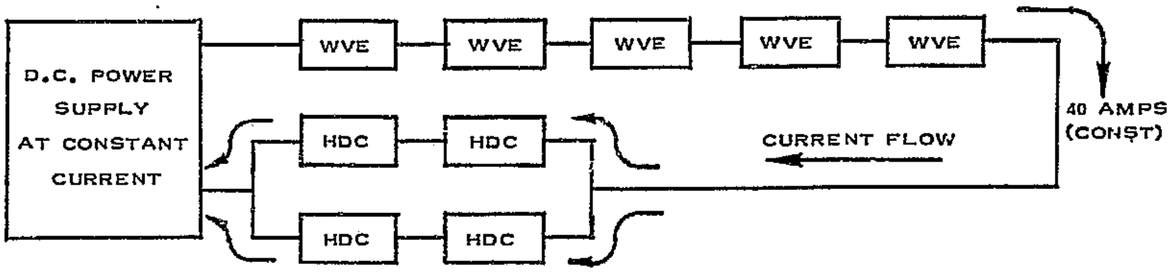
- The WVE/HDC system uses 100 percent of power produced by HDC cells.
- Uses only one power supply and current control. This saves weight and reduces power loss through the inefficiency of additional power supplies, converters and controllers.
- Simple design with minimum controls.

Limitations:

- Both WVE's and HDC's would be operated at the same current level.
- No independent WVE/HDC operation. This would not be a limitation for a flight system, but for an engineering prototype development system, this concept limits the operating flexibility.

The following discussion presents various configurations of the "series" concept which were studied in the power utilization investigation:

Configuration A:



Oxygen Balance (Expressed in Equivalent Amperes)

Available current to produce O_2

$$= 5 \text{ (WVE's)} \times 40 \text{ amps/cell pair} = 200 \text{ amperes}$$

Consumption of O_2

$$= 4 \text{ (HDC's)} \times 20 \text{ amps/cell pair} = -80 \text{ amperes}$$

One man consumption (834 g O_2/day)

$$= 834 \text{ g} \times \frac{1}{7.12 \text{ g } O_2\text{/amps}} = -117 \text{ amperes}$$

$$+3 \text{ amperes}$$

CO_2 Removal

One man production of 1000 g CO_2/day

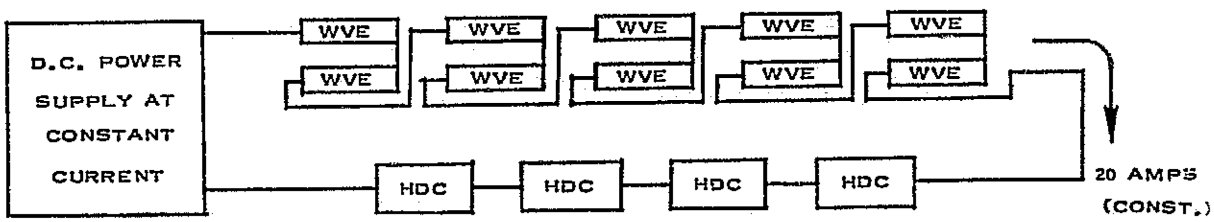
$$= 1000 \text{ g} \times \frac{1}{19.7 \text{ g } CO_2\text{/amps}} = 51 \text{ amperes at 100 percent efficiency}$$

4 (HDC's) x 20 amps/cell pair = 80

$$\eta = \frac{51}{80} = 64 \text{ percent minimum required efficiency}$$

This configuration would provide the oxygen and remove the CO_2 to meet the system requirements. However, the two parallel HDC circuits may not operate at equal currents (because of their differences in resistance) which could result in operating problems.

Configuration B:



The WVE cell pairs in this configuration would be modified to add an electrical insulator in the center of the center housing (cathode current carried) and bolt insulators such that the top cell (one-half square foot effective area) is electrically separated from the bottom cell.

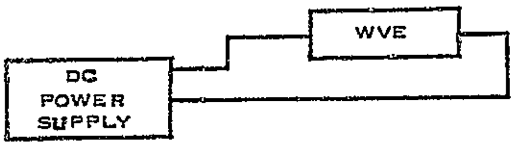
Oxygen Balance

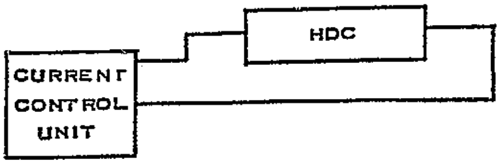
O_2 Production	=	10 (WVE's) x 20 amperes	=	200 amperes
O_2 Consumption by HDC	=	4 (HDC's) x 20 amperes	=	- 80 amperes
One man consumption			=	-117 amperes
				+ 3 amperes

CO_2 Removal (Same as Configuration A)

This configuration would meet all the requirements, while operating both WVE's and HDC's close to their optimum current levels. However, for this program the cost of cell modifications and possible jeopardy to the WVE performance were considered unacceptable.

The power utilization concept that was used for this program uses approximately 20 percent of the HDC output power to control its current level and the WVE's are powered separately.





Advantages:

- HDC's and WVE's can be operated at different current levels.
- Independent WVE/HDC operation.
- Within program scope (funding and schedule).

Limitations:

- Uses only 20 percent of HDC output power and dissipates the remaining power.

The power output of the HDC's sized for a one man system is so small (7 to 18 watts at 18 amperes) when compared to the total system power (represents only two to five percent) that if additional control hardware is required for its utilization, the power savings is lost because of the added weight of the controls. The series operation of the HDC's and WVE's not only utilizes 100 percent of the HDC power output, but it also eliminates a current control unit thereby reducing the system's weight.

Other concepts, such as parallel HDC and WVE operation, would require complex electrical controllers for matching the power levels of each loop in addition to a WVE power supply. Because of this additional system weight and control complexity, these concepts were not considered feasible for a one man system.

The most efficient means for conserving total system power is not in the utilization of the HDC output power but in the power required to make up the oxygen which the HDC cells consume. For example, the present One Man E/C ARS is designed to remove 380 sccm of CO_2 by operating the HDC's at 18 amperes with a CO_2 removal efficiency of 71 percent. The total HDC power requirement for this operating condition, assuming 100 percent utilization of the HDC output power is:

Oxygen Consumption

(4 HDC cells) (18 amperes) = 72 amperes.
O_2 consumption which for the present
WVE cells would require 1.8 volts:
(72) (1.8) = 130 watts

HDC Output Power

(4 HDC cells) (18 amperes) (0.1 volt) = 7.2 watts

Total Power Charged to HDC

130 watts - 7.2 watts = 122.8 watts

In order to reduce this power, the HDC's would have to be operated at a lower current and its CO_2 removal efficiency would have to increase. Parametric test results obtained during the 90-day system test program revealed that the CO_2 removal efficiency does peak at a lower operating current. If, for example, the HDC had a CO_2 removal efficiency of 91 percent (which provides 380 sccm CO_2 removal) at 14 amperes, the total HDC power use would be:

Oxygen Consumption

(4) (14) = 56 amperes which would
require a WVE voltage of 1.7 volts:
(56) (1.7) = 95.2 watts

HDC Output Power

(4) (14) (0.1) = 5.6 watts

Total Power Charged to HDC

95.2 watts - 5.6 watts = 89.6 watts

This type of reduction in power (122.8-89.6) represents a 27 percent savings where the full utilization of the HDC output power provides only a five and one-half percent savings (7.2/130).

This analysis of HDC power conservation versus the peak CO_2 removal efficiency is shown in figure 13. This figure is a plot of the wasted power (in watts) as a result of the oxygen consumed by the HDC, versus the HDC CO_2 removal efficiency (in percent), at various inlet air P_{CO_2} levels and HDC operating currents. These curves were derived from data obtained from the 90 day test program.

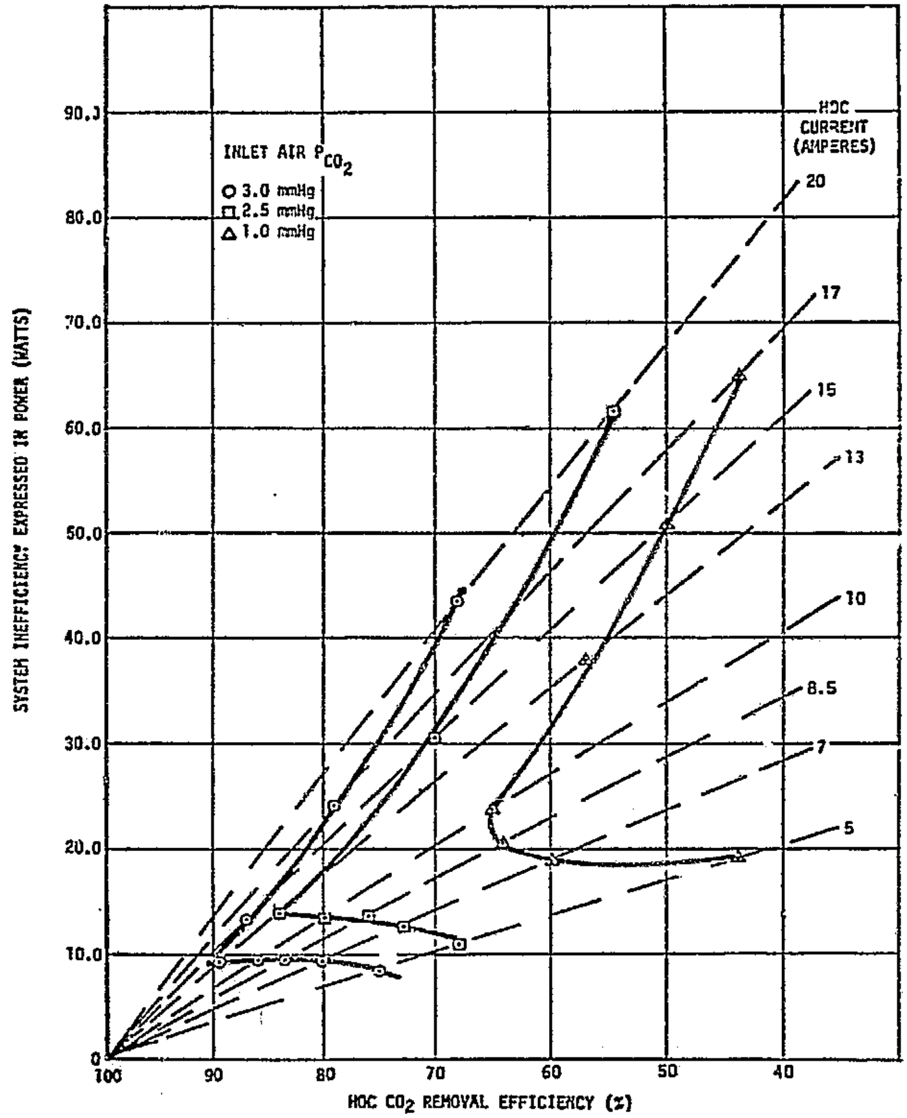


FIGURE 13 SYSTEM POWER INEFFICIENCY VS HDC CO_2 REMOVAL EFFICIENCY

Detail Design & Component Descriptions

The detail design effort of the program consisted of detail designing of the various items of the system and the selection of off-the-shelf items. The following is a description of the items associated with the two packages.

Cell Pair Package

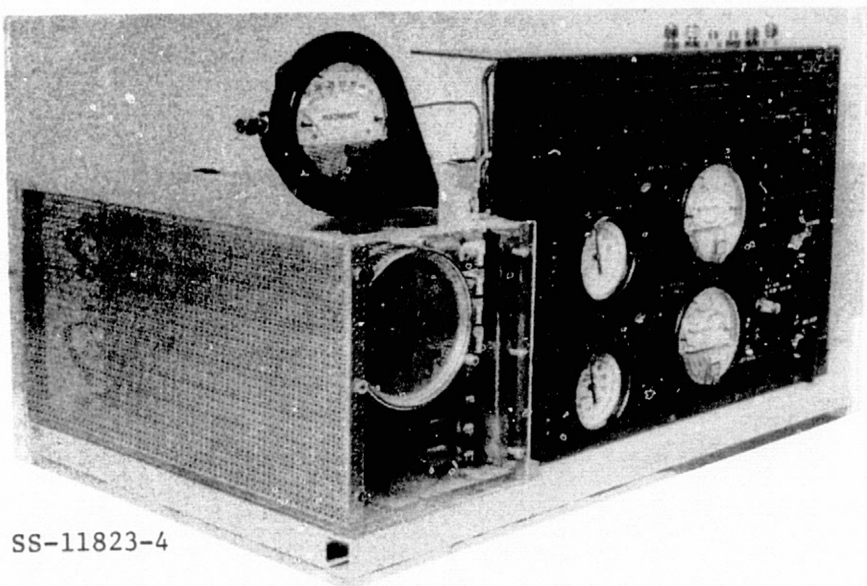
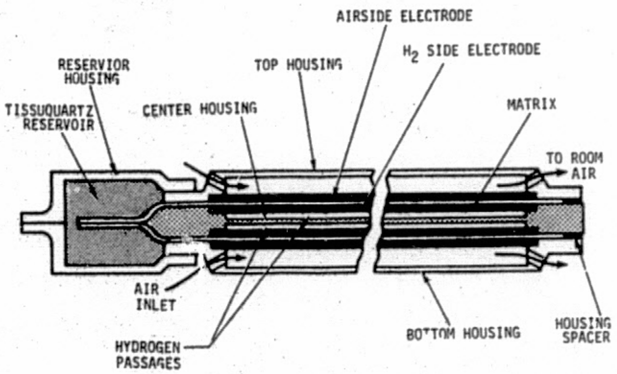


FIGURE 14 CELL PAIR PACKAGE

Package assembly definition and associated item details were manufactured per drawing SVSK 88484 and parts list.

Electrochemical Cell Pairs.- The design of the WVE and HDC cell pair was done on previous NASA programs. As previously noted in the design requirements, the existing cell pair hardware was to be used on this program. These existing cell pairs (per drawing SVSK 88486) were modified as shown in figure 15, to incorporate: a larger reservoir, a change in the mounting brackets and electrical leads, an air baffle, and electrode and matrix materials changes.



CELL PAIR	AIR SIDE ELECTRODE	H_2 SIDE ELECTRODE	MATRIX	HOUSING SPACER	ELECTROLYTE
WVE	ANODE E-2	CATHODE PLAT.	TISSUQUARTZ ASBESTOS NEOPRENE	0.0[illegible]0	H_2SO_4
HDC	CATHODE DC16-0	ANODE PPF & DS16-0 (1)	ASBESTOS NEOPRENE TISSUQUARTZ ASBESTOS NEOPRENE	0.020	TMAC

(1) TWO HDC'S USE PPF ANODES & TWO USE DS16-0 ANODES

FIGURE 15 ELECTROCHEMICAL CELL PAIR

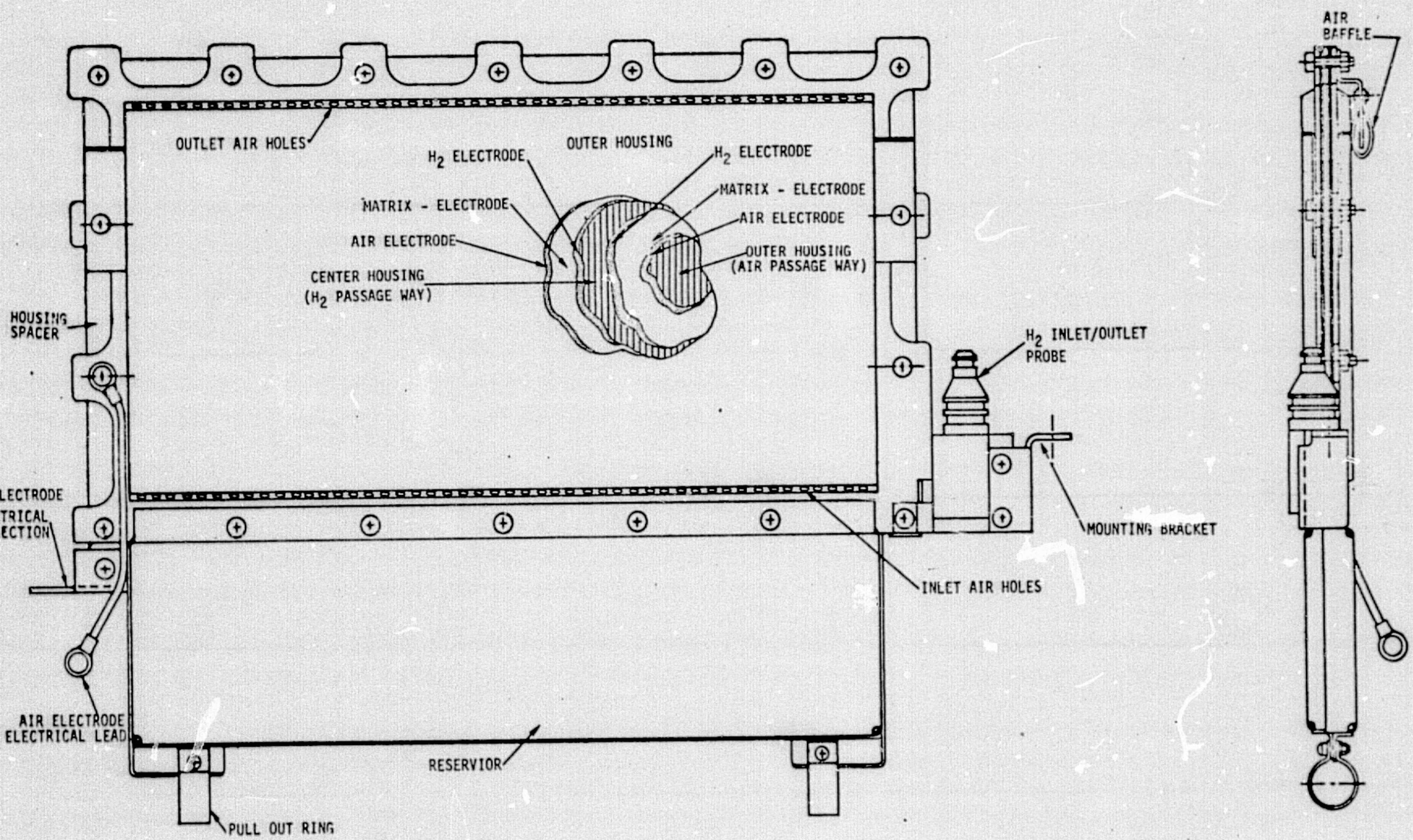


FIGURE 15 ELECTROCHEMICAL CELL PAIR "CONCLUDED"

Cell Pair Rack & Manifold Housing.- This "plexiglass" housing holds the WVE and HDC cell pairs in a horizontal position. Grooves were machined on the inside surface of vertical sides to provide a slot into which the cell pairs center housing tabs slide. The grooves are spaced 2.54 cm (1.0 inches) apart which allows the cell pairs to be inserted and provides a light compression of the cell pairs air baffle between the two inserted cell pairs.

The H_2 manifold on the side of the housing has eight socket ports into which the cell pair H_2 probe is inserted when the cell pair is slid into the rack. The top four ports are manifolded to provide parallel H_2 flow from the WVE cell pairs. The bottom four ports are manifolded to provide series H_2 flow through the HDC cell pairs. This manifolding is done by a series of drilled passages. Two tapped holes on the side of the housing were machined for mounting dial thermometers and a third hold tapped on the rear of the housing for mounting the combustible gas sensor. The rear side also has a large diameter hole for the connection of the inlet duct of the blower.

Provisions are made for mounting various brackets for securing the cell pairs and terminal boards for instrumentation wiring.

The housing is mounted on top of the package unistrut frame which allows easy handling of the complete package.

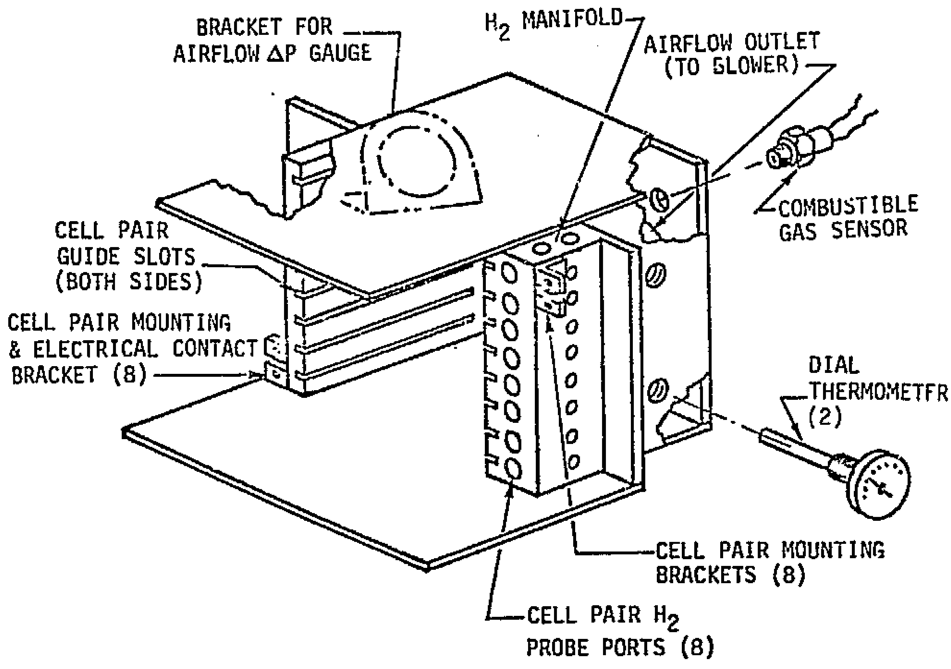


FIGURE 16 CELL PAIR RACK AND MANIFOLD HOUSING

Valve and Gauge Panel.- The aluminum package panel provides the mounting surface for the package valves, gauges and plumbing. The panel is secured to the unistrut package frame and to the cell pair rack housing. A photo-etched aluminum label of the H_2 flow schematic is bonded to the panel for quick reference when adjusting the various valves.

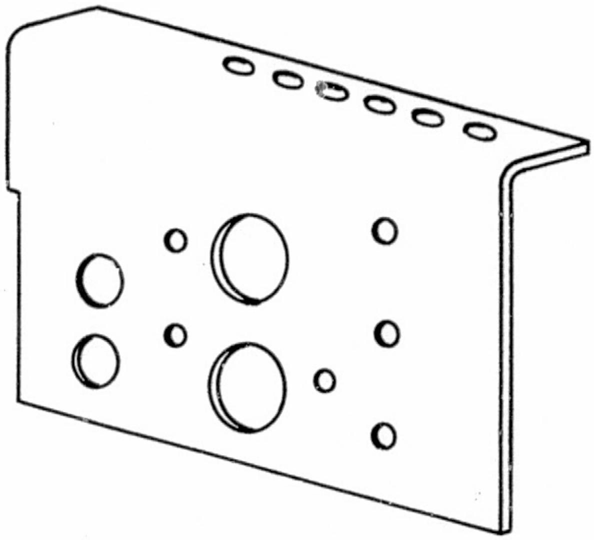


FIGURE 17 VALVE AND GAUGE PANEL

Inlet Cover/Grill.- The inlet cover/grill protects the cell pairs and their associated connections. This plexiglass cover also provides the mounting surface for the inlet air relative humidity and temperature gauge. The protective grill is made of aluminum.

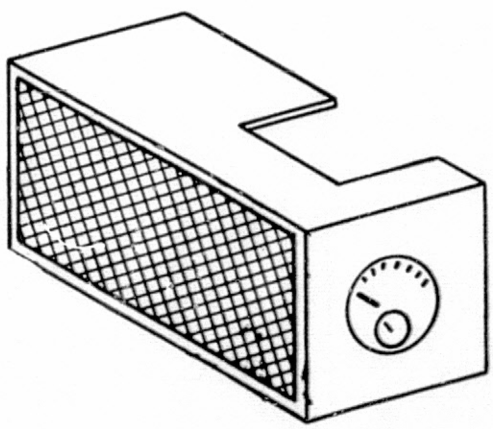


FIGURE 18 INLET COVER/GRILL

H_2 Filter.- The H_2 filter (per figure 19) consists of two concentric cylinders that are bonded to the inlet/outlet end cap. The base cap and viton gaskets seal the other end of the cylinders. The two end caps are secured to each other with three tie rods. This filter was added to the HDC inlet H_2 plumbing to scrub any possible traces of H_2SO_4 which might come from the WVE. The LiOH bed will absorb any acid type particles and the activated carbon will absorb any other undesirable gas. The pressure drop through this filter is less than 0.547 kPa (2.2 in. H_2O) at flow rates up to 2000 sccm.

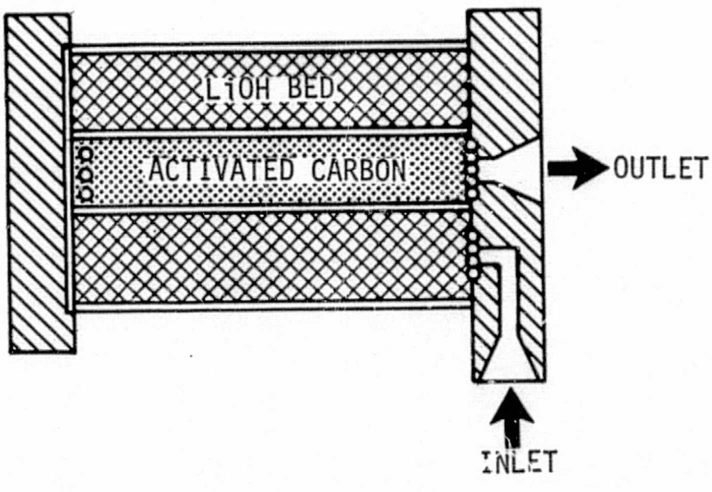


FIGURE 19 H_2 FILTER

Manual On-Off Valves.- (Items* 4**, 11, 14, 15 & 16) - Mfg., Whitev P/N's SS43XS4*, SS4152 & SS4354. These are ball-type valves incorporating 316 stainless steel bodies and teflon packing seals. These valves provide maximum corrosion resistance, high reliability and quick acting on-off operation (one quarter turn).

Metering Valves.- (Items 2, 12 & 13) - Mfg., NUPRO P/N's SS4MX & SS4MG. These needle valves incorporate 316 stainless steel body and stem with viton seals. These valves regulate an orifice from 0.00 cm dia. to 0.1397 cm dia. (0.00 to 0.055 inches) through ten turns of the stem.

Check Valves.- (Items 14A & 19) - Mfg., NUPRO P/N SS-4C 1/3. These check valves are 316 stainless steel housing and poppet, and use buna "N" seals. The cracking pressure is 2.06 kPa (0.30 psi) with minimum pressure drop at full flow.

Relief Valves.- (Items 9 & 10) - Mfg., Circle Seal P/N 532T-2MP-4. The relief valves are 316 stainless steel housing and poppet, and use Viton seals. Cracking pressure is adjustable from 17.2 kPa to 40.5 kPa (2.5 to 5.9 psi) with zero leakage at 95 percent of the cracking pressure. The relief adjustment is internal to the valve, requiring the removal of the valve from the system.

Inlet Filters.- (Items 20 & 21) - Mfg., NUPRO P/N SS4FR-7. The inlet filters are in-line removable filters which provide means of replacing the filter element without removing the filter from the system. Housings made of 316 stainless steel, Vitron "A" seals and a 316 sintered stainless steel element.

Solenoid On-Off Valves.- (Items 1 & 11A) - Mfg., Skinner Valve P/N's V51DA 2125 (non-open) & V52DA 2125 (non-closed). The solenoid operated valves incorporate 110 Vac continuous duty solenoids, 316 stainless steel bodies and plunger, and Viton seals. The valves have a 0.238 cm dia. (3/32 inch) orifice and are rated for 858.8 kPa (125 psi) operating pressure.

**This is a three-way valve of similar design and has a one-half turn movement.

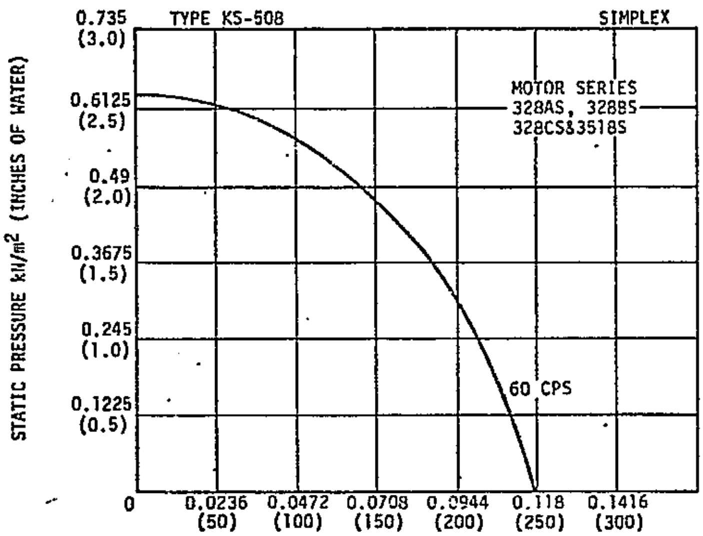
*Item numbers of this section correspond to the components of Figure 2.

Pressure Gauges.- (Items 17, 18 & 22) - Mfg., Dwyer P/N's 2202 & 2205. The "Magnehelic" pressure gauge consists of two pressure-tight compartments separated by a molded flexible diaphragm. The interior of the gauge case serves as the "high" pressure compartment and a sealed chamber behind the diaphragm serves as the "low" ambient pressure compartment.

Differences in pressure between the high and low sides of the diaphragm cause the diaphragm to assume a balanced position. The front support plate of the diaphragm is linked to a leaf spring that is calibrated through a magnetic linkage to the indicating pointer.

Pressure Regulator.- (Item 8) - Mfg., TESCOM P/N 22640. This backpressure type regulator uses 316 stainless steel bore and a plunger, a teflon seat and a Viton "A" diaphragm. The regulator has been modified to provide regulation between 6.89 to 34.5 kPa (1 to 5 psi) backpressure. It incorporates a sensitive diaphragm with a large sensing-to-seat area ratio which provides a low crack pressure to reseat pressure differential and better repeatability.

Blower.- (Item 27) - Mfg., Rotron P/N KS-508. The air blower is a simplex squirrel cage blower driven by a 115 Vac motor. This blower incorporates a bell inlet cone and a flanged outlet port. The performance is given below.



AIR VOLUMETRIC FLOW RATE-METER^3/SEC - (CFM)

FIGURE 20 ROTRON BLOWER PERFORMANCE

Air Flow Sensor Switch.- (Item 28) - Mfg., Rotron P/N 4000 Series. This electrical switch actuates purely on air velocity and is not influenced by stall pressure. The lightweight stainless steel vane which protrudes into the exit airstream moves as a function of air flow. This movement actuates the switch which can be wired for normally open or closed positions.

Combustible Gas Sensor.- (Item 26) - Mfg., General Monitoring, Inc. P/N Standard Model 180-10-001-1. The combustible gas sensor will detect any combustible gas mixtures and transmit an electrical signal to the combustible gas controller. The sensor is a low temperature, catalytic bed, diffusion type unit, having a one second (using H_2) response time.

H_2 Flow Sensor.- (Items 5 & 7) - Mfg., Tylan Corporation P/N Model 420-G. The H_2 flow sensors consist of a base assembly which contains the sensing elements, gas fittings, electronics to condition and amplify the flow signal, and a cover. When a low dc voltage (power supply located in Instrumentation/Control package) is supplied to the sensor, there is an output voltage from 0 to 5 Vac, linearly proportional to the flow, which is transmitted to the voltmeter on the Instrumentation/Control package. Adjustments are provided for zero, linearity and gain.

Principle of Operation.- When heat is applied to a gas stream, the temperature rise is a function of the mass flow rate, the thermal properties of the gas, and the amount of heat added. This principle is applied in this sensor which is a small stainless steel tube with two resistance thermometers wound on the outside. A few milliwatts of heat applied by the sensor raises the gas temperature slightly, changing the relative reading of the two thermometers. The design parameters are such that the temperature difference signal between the resistance thermometers is directly proportional to flow and is also linear. Since different gases have different thermal properties, each flowmeter is calibrated with the actual gas to be used. To vary the flow range, an internal divider splits the gas stream in an exact ratio between the sensor and bypass. The bypass matches the linear flow characteristics of the sensor. Since it is a laminar flow element (in contrast to an orifice), accuracy is maintained over the complete temperature range.

Dial Thermometers.- (Items 23, 24 & 25) - Mfg., Cole Parmer P/N's 8123-40 & 3310. The air outlet thermometers (8123) have a hermetically sealed 304 stainless steel case and a stainless steel probe. The case has a base with a one-half NPT connector for mounting. The dial reads from 25°F (-4°C) to 125°F (51°C) and has an accuracy of one percent.

The inlet air thermometer/relative humidity meter (3310) has a solid brass housing which contains the two dials. the air temperature dial reads from -10° (-23°C) to 190°F (88°C) and the relative humidity dial reads from zero percent to 100 percent.

Instrumentation/Control Package

The panel layout, electrical schematic and package parts list are defined on drawing SVSK 88485. The assembly of the electronic components into the system was done by detail functional groupings; (1) the instrumentation power supplies were mounted to the side of the cabinet and the WVE power supply mounted at the bottom of the cabinet because of its weight, (2) the instrumentation meters/switches were mounted on the cabinet panel, and (3) the system logic, control and calculating functions were located in a separate chassis (25.4 x 35.5 x 7.6 cm) 10 x 14 x 3 inches which was in turn mounted to the top of the cabinet.

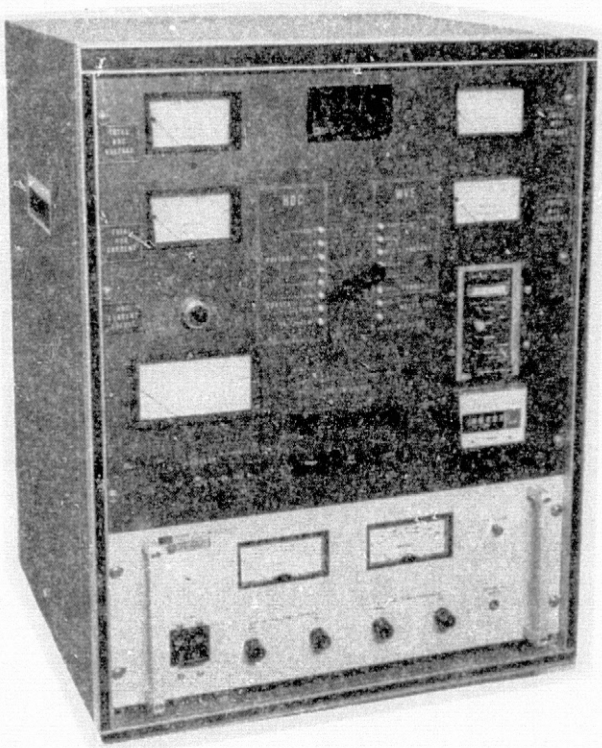


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FIGURE 21 INSTRUMENTATION/CONTROL PACKAGE

Cabinet.- (Item* 13) - Mfg., Premier P/N TIC 241917. Standard metal instrument case for 48.26 cm (19 inches) wide x 43.18 cm (17 inches) depth panel mounted instruments. Maximum panel height is 62.2 cm (24 1/2 inches).

Package Display Panel.- The aluminum package display panel provides the mounting surface for all the meters (8), indicator lights (4), miniature marking lamps (16), push button switches (3), two position selector switch (1), HDC current control knob (1), fourteen position selection switch (1), and a stepping relay (on back side of panel). The panel is mounted to the front of the cabinet with six screws.

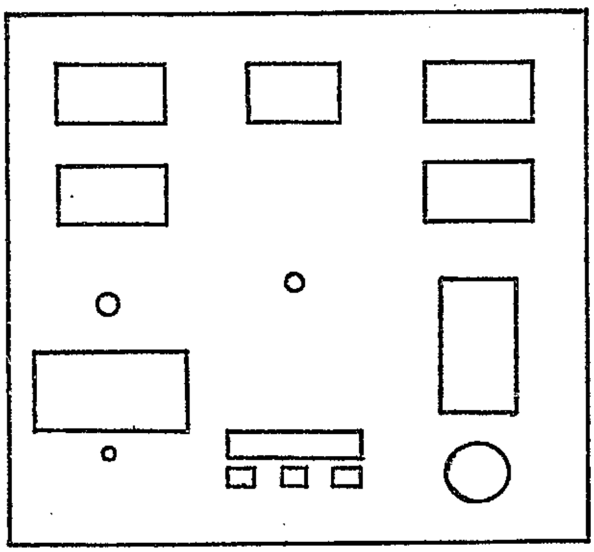

FIGURE 22 DISPLAY PANEL

Digital Meter.- (Item 15) - Mfg., Analog Devices P/N AD 2004. This meter provides a five digit plus sign and decimal point display. The input range is 0 to 1.9999 volts. If this range is exceeded, a four digit display of zero will flash on and off until the input is within the required operating range. The accuracy is 0.01 percent of reading the last digit. This unit also requires a 5 Vdc ± 5% @ 1.40A power source.

dc Volt & Amp Meters.- (Items 1, 2, 11 & 12) - Mfg., Simpson P/N's 9720 & 9730 (Vac), and 2710 & 2740 (Adc). These meters are bezel mounted "wide-VUE" meters which incorporate shielded movement that prevents the calibration and meter reading from being affected by stray magnetic fields. The ranges are: 9720 (Vac) 0-5, 9730 (Vac) 0-8, 2710 (Adc) 0-25, 2740 (Adc) 0-100.

*Item numbers of this section correspond to the components of Figure 9.

Elapsed Time Meter.- (Item 9) - Mfg., Simpson P/N 03595. This panel mounted meter displays the accumulative "on" time of the system up to 99,999.90 hours. The meter operates on 120 Vac, 60 Hz power and indicates the time to 0.1 of an hour.

Flow Meter.- (Item 4) - Mfg., Tylan P/N Model 420-G. This is a bezel mounted direct current voltmeter (0-5 Vac) which has the meter face changed to display a 0 to 2000 sccm calibration. The meter receives a 0-5 volt signal from the flow sensor on the cell pair package.

Combustible Gas Meter.- (Item 10) - Mfg., General Monitors, Inc. P/N Model 180. The combustible gas meter monitors the output of the combustible gas sensor located in the cell pair package. By analyzing the sensor signal this unit will display the concentration level of the combustible gas (H_2) that is present. The meter range is 0 to 100 percent lower explosive limit which for H_2 (at 100 percent lower explosive level) is 5 percent to H_2 by volume in the air. In addition to the display meter this unit provides for other light displays; green light for normal operation, blue light for a malfunction of the unit, amber light to indicate that the low level (adjustable) has been reached, and a red light indicates that the high level (adjustable) has been reached. The unit is wired to shut down the system and actuate a warning buzzer when the low level (10 percent lower explosive limit) has been reached.

Indicator Lights & Push Button Switches.- (Items 7 & 8) - Mfg., Micro Switch P/N 4A21B31DWK (Lights) & 4A21BEA (Switch). The indicators and switches are a flat black assembly with caps that light up in various colors and display a legend when actuated. The legend on the indicators are hidden until the unit is actuated. The legend on the push buttons are always visible. The following is a description of each unit.

Indicator Lights.-

Legend		Color When On
Power Loss	-	White
H_2 Leak	-	White
Air Flow	-	White
WVE Power	-	White

Push Buttons			Type of Switch
Power	-	Green	2 pole (DPDT) momentary
System Start	-	Blue	2 pole (DPDT) alt. action
Stop	-	Red	2 pole (DPDT) momentary

Selector Switch.- (Item 14) - Mfg., Micro Switch P/N PA-3007. This seventeen position switch is a four-pole, four-section rotary switch used to select the various system performance parameters for display on the digital meter (item 15).

Stepping Relay.- Mfg., C. P. Clare P/N SS255. This is a twenty position stepping relay of which only sixteen positions are used. This relay will automatically select each system performance parameter in turn and display it on the digital meter for four seconds. The cycling of the relay every four seconds and the fast cycle through the switch positions which are not used is done by an electronic circuit that was added to the unit.

HDC Current Control Adjustment.- (Item 3) - Mfg., Bourns P/N 35075-1-103. The HDC current control adjustment is done by adjusting the potentiometer (10 k, 10 turn linear unit) to the proper balancing voltage that controls the HDC current to the desired value.

WVE Power Supply.- (Item 6) - Mfg., Hewlett Packard P/N 6260B. This is a rack-mounted direct current power supply unit of 0-10 Vac and 0-100 amperes, using 220 Vac as the input. This power supply has been factory modified to allow automatic current programming. This feature is used on system shutdown when it is desired to reduce the WVE input current to zero, prior to shorting out the WVE's. The power supply was procured by NASA JSC and supplied as Government furnished equipment to this program. (NASA Product Control No. 99697).

Control Power Supplies.- Mfg., DYNAGE, Inc. P/N's MB 5-6, MB 23-24 & (3) MA 5-15. These control direct current power supplies provide the necessary reference and drive powers which the various electronics require. The following control power is provided.

MB 5-6	5 volts @ 6 amperes
MB 23-24	24 volts @ 2.30 amperes
MA 5-15 (3)	5 volts @ 6 amperes (2) 15 volts @ 1.30 amperes (1)

Shunts.- Mfg., Simpson P/N's 6713 & 6709. The shunts are used to measure the WVE and HDC currents.

WVE current (to meter)	P/N 6713 - 100 amps/50 mV
HDC current (control logic only)*	P/N 6709 - 50 amps/50 mV

Cooling Fan.- Mfg., Rotron P/N Type 103 (Feather). This is a 17.78 cm (7 inch) diameter fan using 110 Vac, 60 Hz power - a three-bladed fan used for cooling the electronics.

*The HDC ammeter has a shunt incorporated within the meter.

SYSTEM FABRICATION

The fabrication task consisted of hardware procurement and manufacturing, cell pair assembly and system package assemblies.

Cell Pair Assembly

Modification and refurbishment of the existing cell pair housings was required. This consisted of increasing the air hole size from 0.2286 mm (0.090 inches) to 0.356 mm (0.140 inches) diameter, changing the serpentine H_2 flow path of the center housing to make a serpentine path of three parallel cross flows instead of one, cleaning and replating the housings, and adding a 0.0254 mm (0.001 inch) thickness of baked-on teflon on the sealing surface of the outer housings.

The various type of electrodes were fabricated for the WVE and HDC at Hamilton Standard and at Pratt & Whitney Aircraft, South Windsor Engineering Facility. During the second and third rebuilds of the HDC cell pairs, additional electrodes were fabricated.

A typical HDC cell pair layout prior to assembly is shown in figure 23 and at various stages of the assembly in figures 24 and 24A. Upon completion of the assembly of a cell pair it was checked for electrical shorts and leak checked at 68.7 kPa (10 psi) pressure differential across the matrix.

System Package Assemblies

After the procurement and manufacturing of the detail hardware was completed, the two main assembly efforts were the plumbing of the cell pair package and the wiring of the instrumentation/control package (reference figures 25 and 26).

The plumbing was done using stainless steel tubing and "Swagelok" tube fittings. After the initial plumbing was completed the plumbing was completely disassembled and the tubes were all cleaned. After the reassembly of the plumbing, the system was functionally checked out and leak tested. The final hook-up of the H_2 lines to the cell rack/manifold housing was done after the housing and blower were secured to the base/frame. As the cell pairs completed their conditioning tests, they were inserted into the cell pair racks and prepared for the start of the system check out.

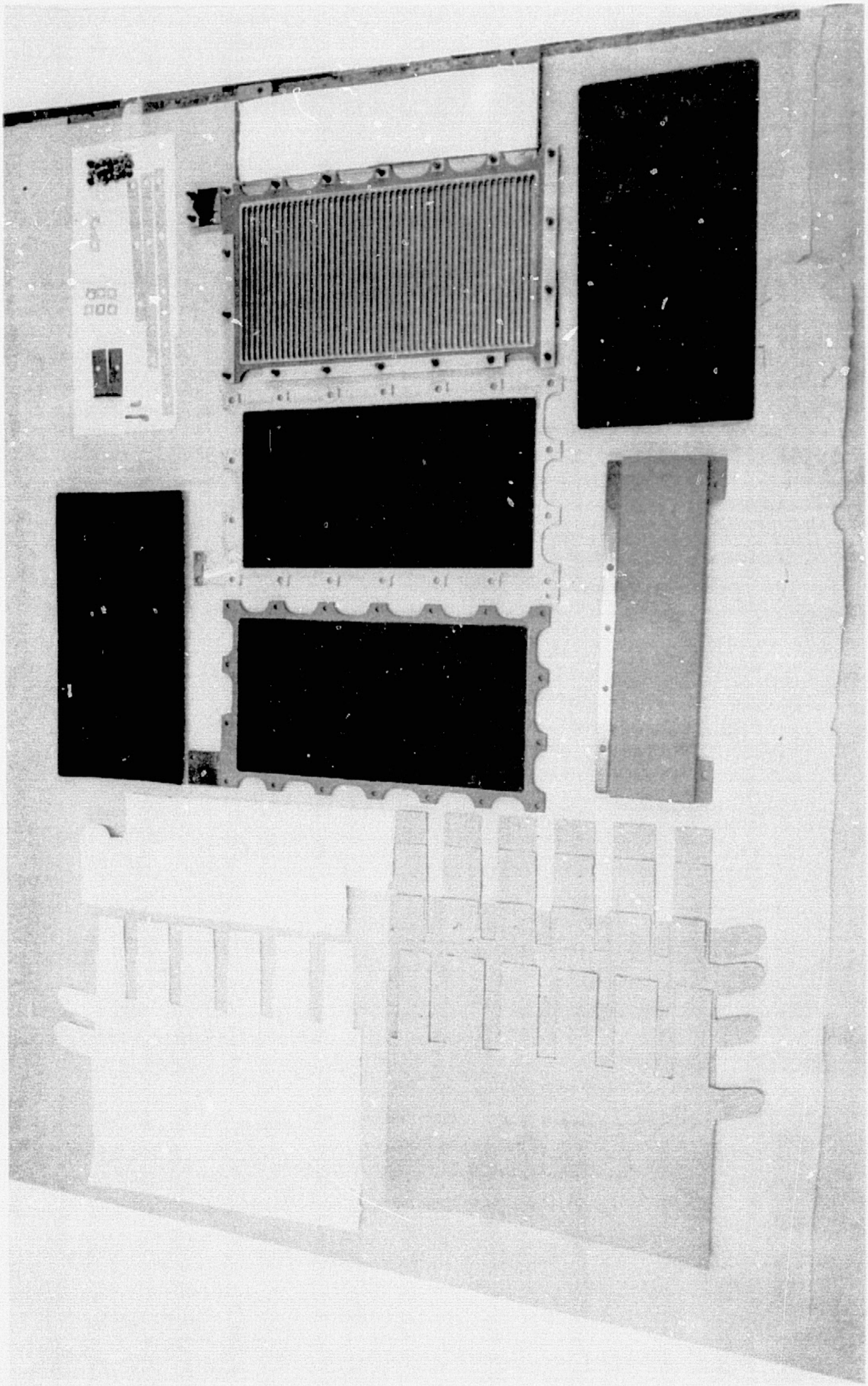

FIGURE 23 DETAILED CELL PAIR HARDWARE LAYOUT

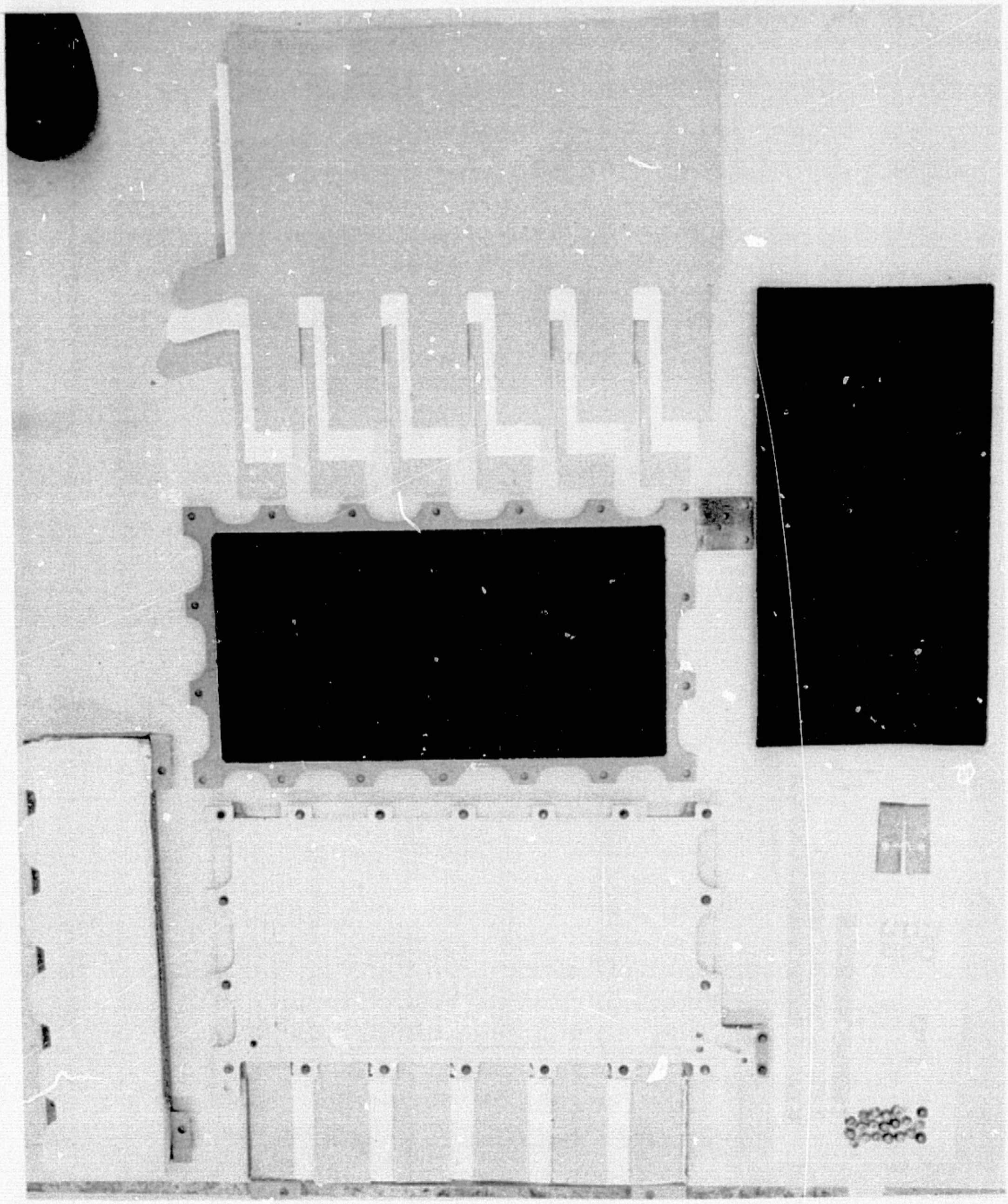

FIGURE 24 CELL PAIR PARTIAL ASSEMBLY

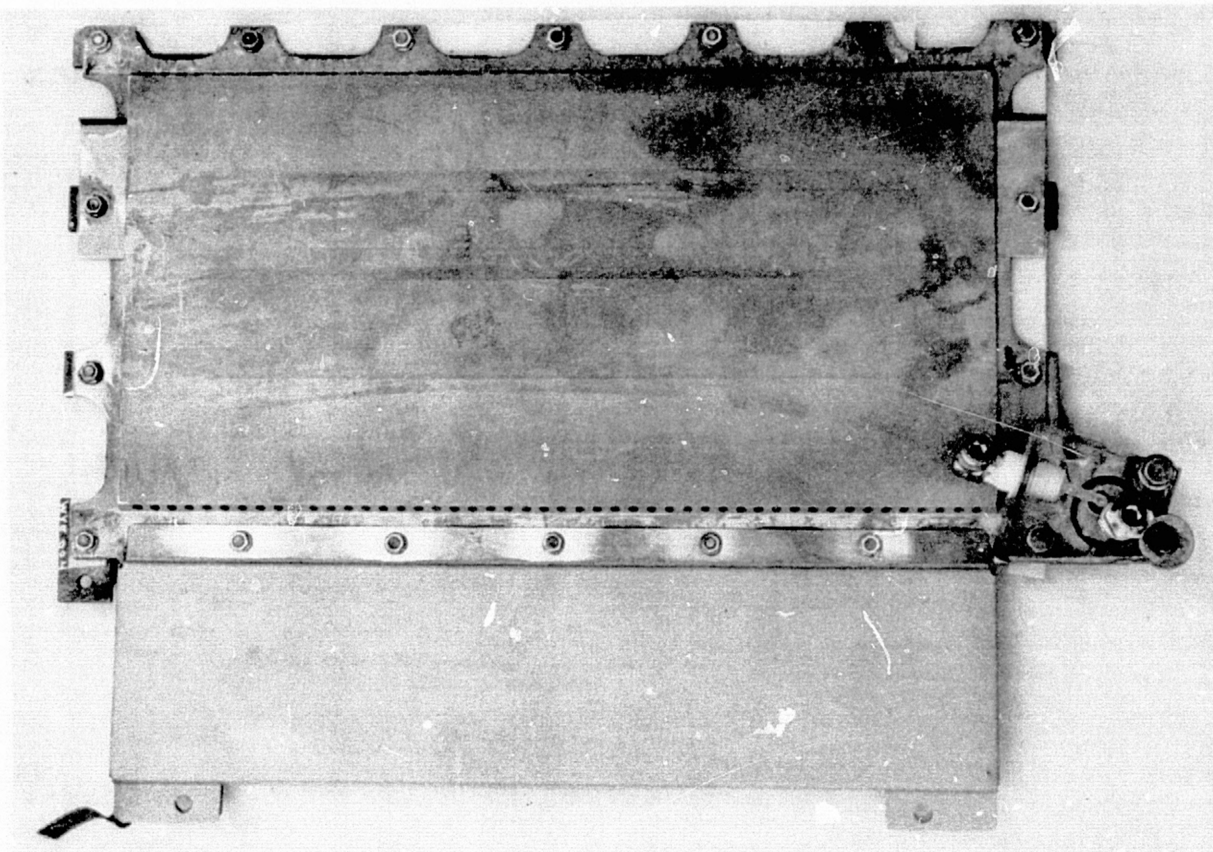

FIGURE 24A CELL PAIR ASSEMBLED

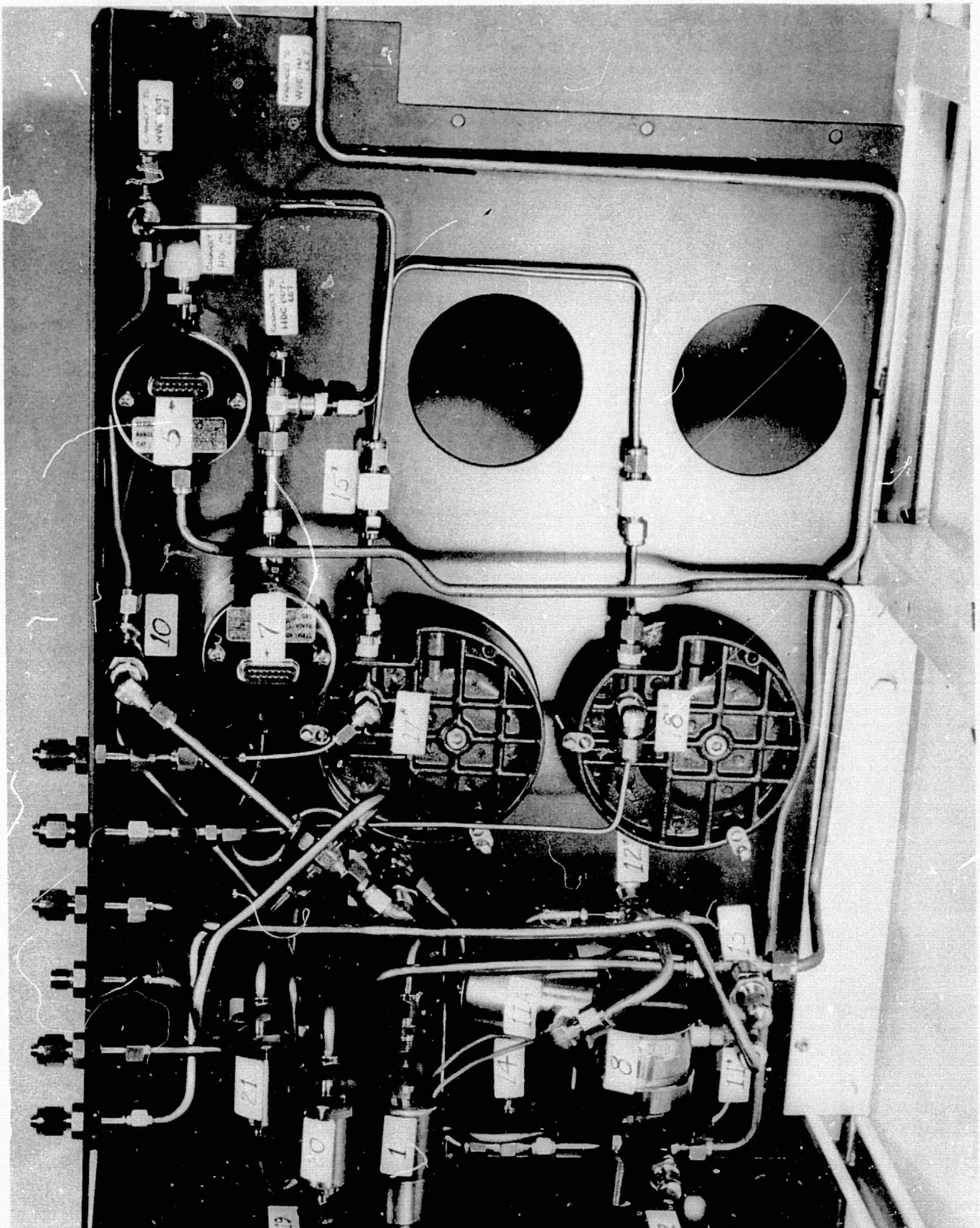

FIGURE 25 PLUMBING VIEW OF CELL PAIR PACKAGE

Mounting and wiring of the many electrical components in the electronic chassis was the major task of the instrumentation/control package assembly. As each circuit was completed and checked out, the various system operating functions were tested. Simulated system inputs and loads were used during these functional tests. The more complex circuits, (HDC current control; stepping relay; CO_2 removal calculator; etc.) were breadboarded and tested prior to their incorporation into the system circuitry. Some modifications and adjustments were made in the electrical circuitry during the initial testing of the system to reduce line losses and provide better system control.

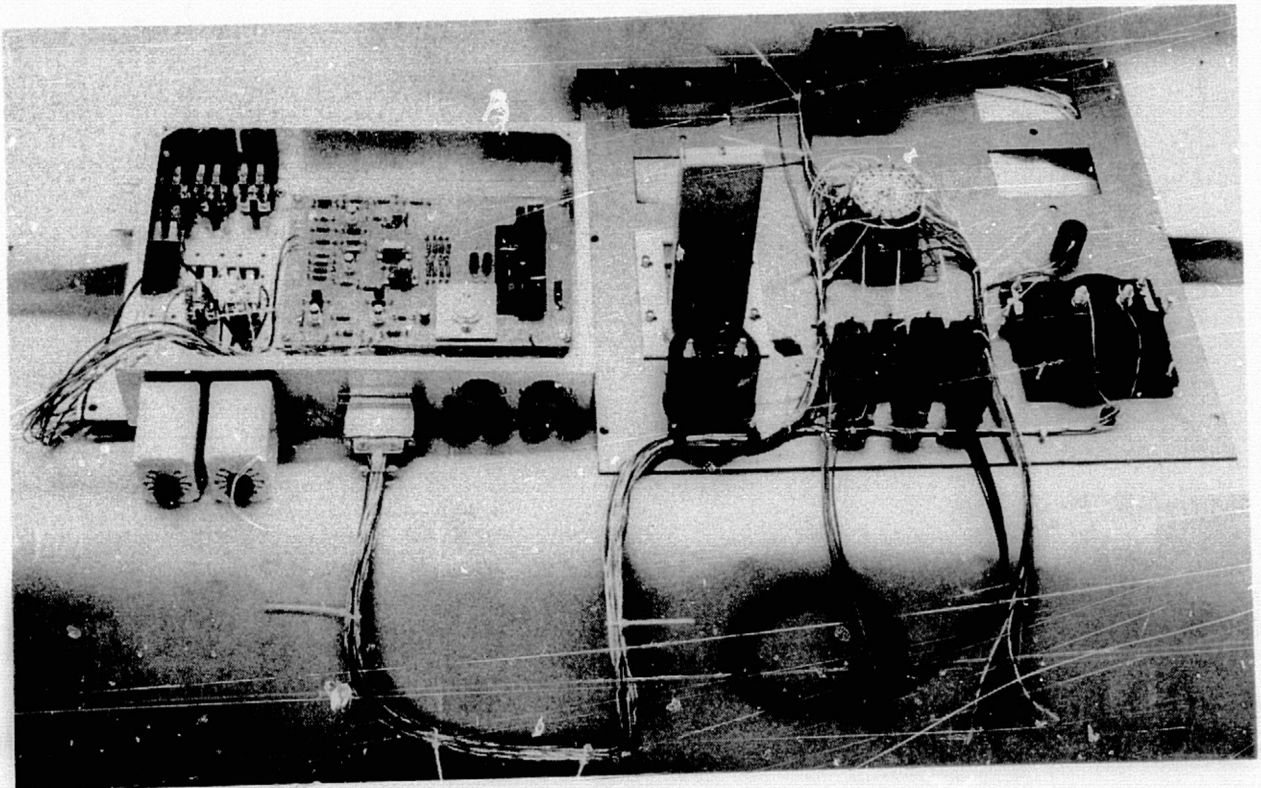

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FIGURE 26 WIRING VIEW OF INSTRUMENTATION PACKAGE

TEST PROGRAM

Testing of the WVE and HDC units under this program was conducted per the program master test plan included in this report as Appendix A. This testing consisted of cell pair conditioning tests and system performance tests. A special HDC test program also was conducted during this program to investigate further performance at the cell pair level. All testing was performed in the Advanced Engineering Laboratories of Hamilton Standard's Space Systems Department. The following discussion presents the performance data obtained during the component and system testing.

Component Testing

Component testing consisted of WVE and HDC cell pair conditioning tests and the HDC performance investigation. The purpose of the cell pair conditioning test was to condition the electrolyte in the cell to the maximum relative humidity level under which it would operate (maximum electrolyte volume). Conditioning the cell pair at this high a relative humidity provided the assurance that electrolyte would not be lost (cell flooding) during future operation at equal to or lower relative humidity levels. The component testing also provided an accept/reject criteria as defined in the test plan (Appendix A) for the cell pair before it started system tests.

WVE Conditioning

WVE cell pair conditioning was performed at an inlet air condition of about 88 percent relative humidity and 294.25 K (70°F) dry bulk temperature, and an operating current of 50 amperes. The H_2 backpressure of 107.8 kPa (15.70 psia) was maintained on the unit during the test.

The performance of the four WVE cell pairs as shown in figure 27 ranged between 1.64 to 1.66 Vdc at the end of conditioning, which is within the acceptance requirement of not exceeding 1.70 Vdc. The voltage peaks shown on the second day of testing on S/N 002 and S/N 004 was a result of a low inlet dew point relative humidity of about 40 percent.

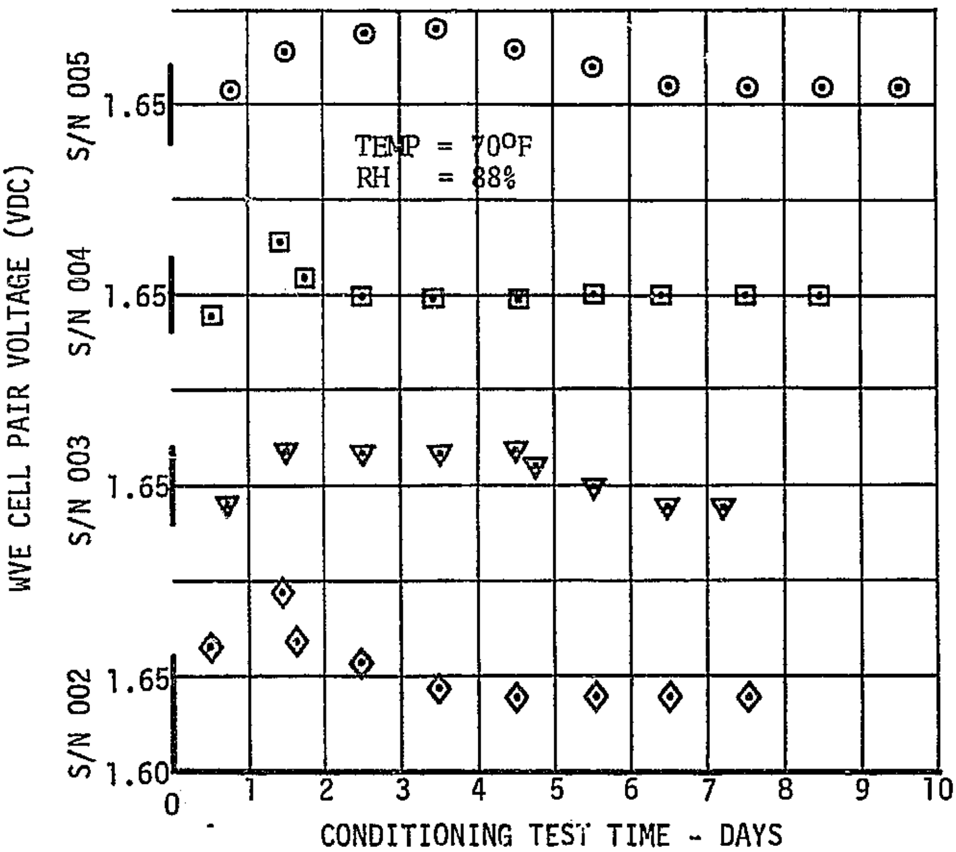

FIGURE 27 WVE CELL PAIR CONDITIONING

HDC Conditioning

There were three series of HDC cell pair conditioning tests conducted. The first conditioning tests were made on cell pairs S/N 025 through S/N 028, the second conditioning tests, four months later, were made on cell pairs S/N 025A through S/N 028A and the last conditioning tests, three months later, were made on cell pairs S/N 029 through S/N 032.

The initial conditioning tests were conducted for approximately one week at a constant HDC current of 18 amperes with inlet air conditions of 0.395 percent CO_2 at one atmosphere, 294.25 K (70°F) dry bulb temperature and 88 percent relative humidity. The performance of the cell pairs as shown in figure 28 reveals an average CO_2 removal efficiency of 75 percent and the lowest steady state voltage of all four cell pairs was 0.200 volts. These cell pairs were acceptable and went on to system testing.

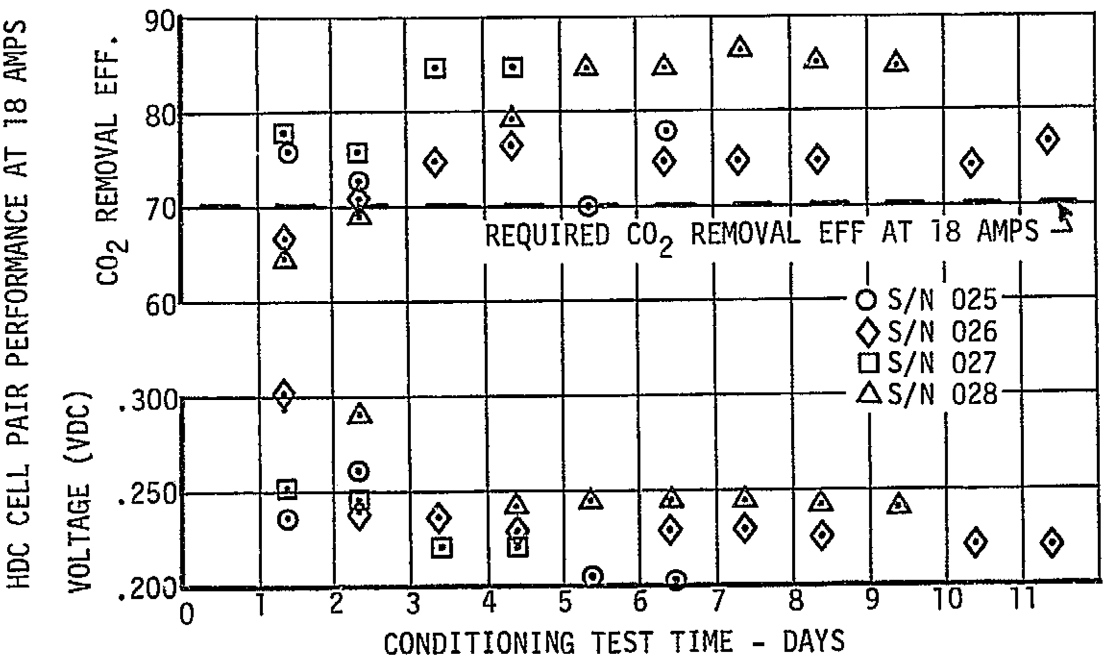

FIGURE 28 INITIAL HDC CELL PAIR CONDITIONING

The HDC cell pairs S/N 025 through S/N 028 were removed from the system testing because of the system malfunction which contaminated the HDC's with WVE electrolyte and were disassembled. The rebuild of these cell pairs included new electrodes and matrix which were made up of the same elements but from different lot numbers. The reassembled cell pairs S/N 025A through S/N 028A were conditioned under the same operating conditions as the initial assemblies, but the performance of the reassembled units was lower than before rebuilding as shown in figure 29. Because of this reduced performance, additional conditioning testing was conducted on three of these cell pairs (S/N 025A, 026A & 028A) as part of the HDC performance investigation.

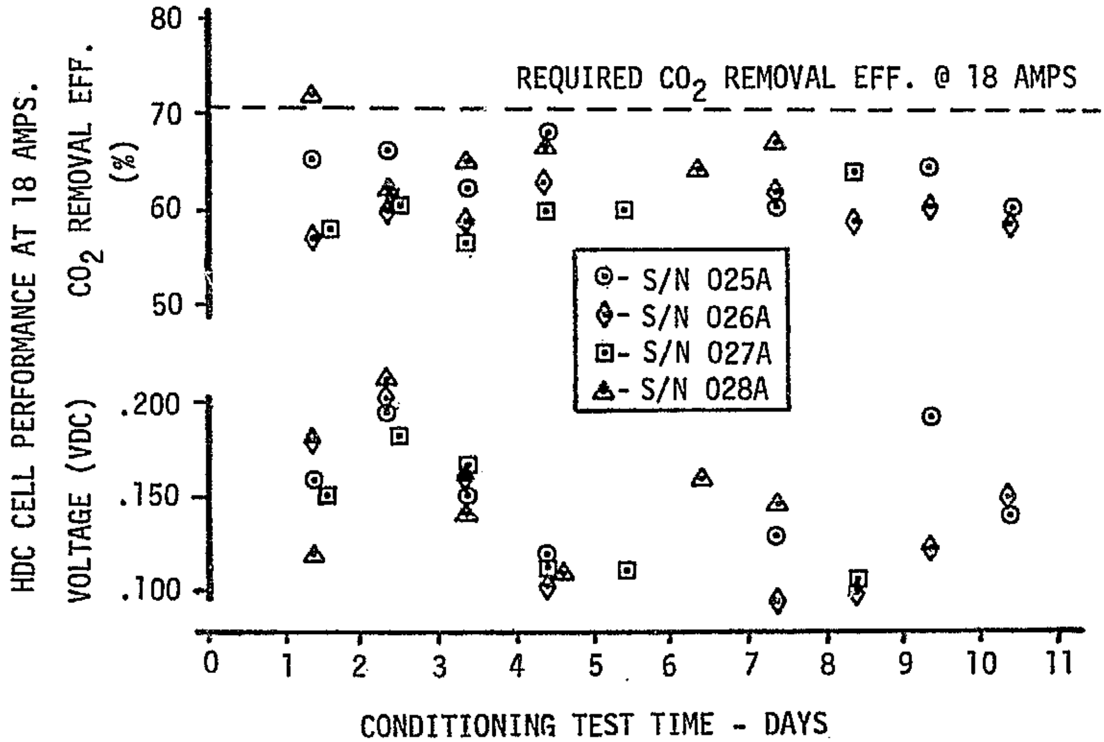

FIGURE 29 HDC CELL PAIR CONDITIONING (SECOND ASSEMBLY)

After the completion of the HDC performance investigation, the HDC cell pair assemblies S/N 025A through S/N 028A were rebuilt in accordance with the recommendations of the investigation. The conditioning of the final HDC cell pairs, S/N 029 through S/N 032, was conducted for at least two weeks and up to three weeks at 18 amperes, with inlet air conditions of 3 mmHg P_{CO_2} at one atmosphere, 294.25 K (70°F) dry bulb temperature and 81 percent relative humidity. The performance of these units, reference figure 30, were satisfactory with CO_2 removal efficiencies of all cell pairs above 70 percent. These cell pairs were placed on system test for the 90-day evaluation program.

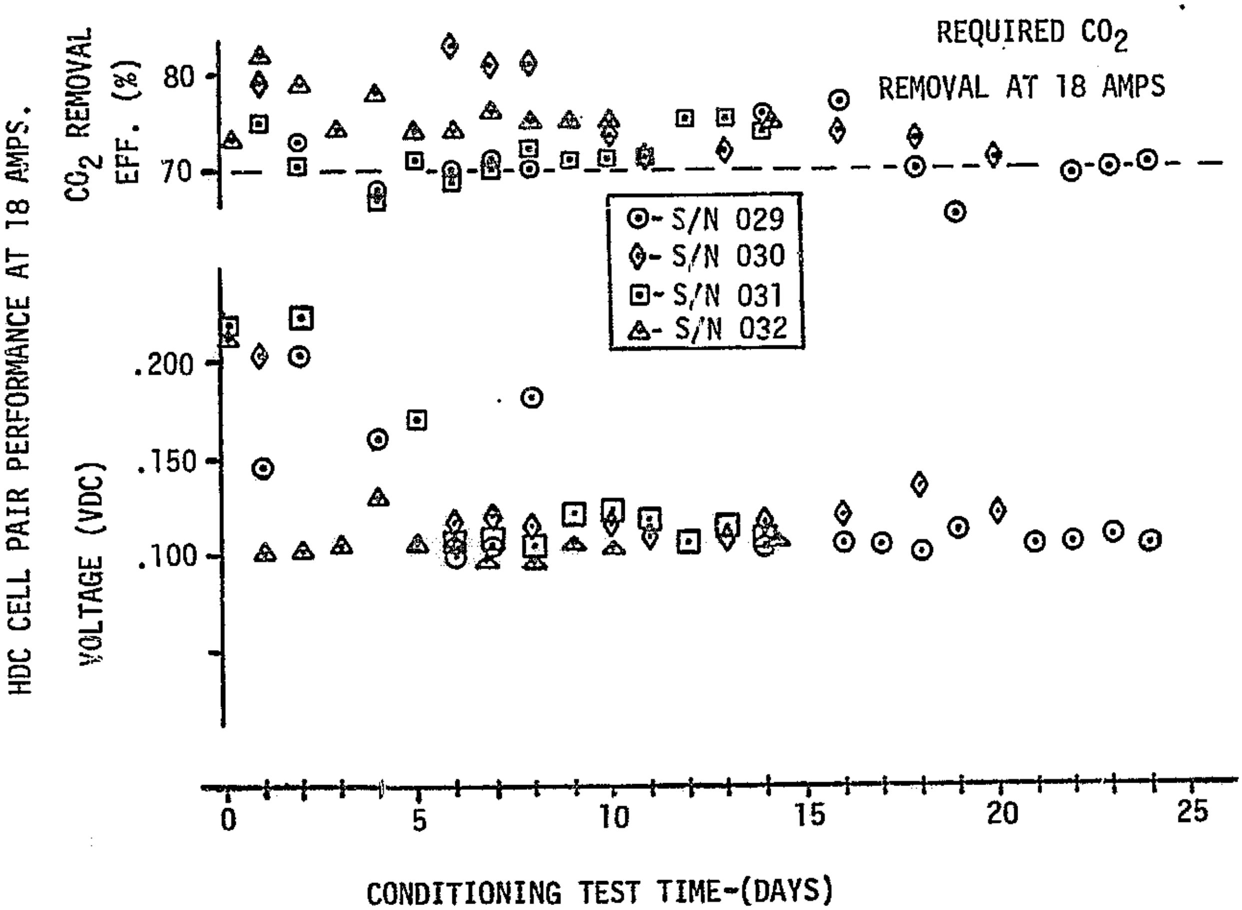

FIGURE 30 HDC CELL PAIR CONDITIONING (FINAL ASSEMBLY)

HDC Performance Investigation

The lower CO_2 removal rate and output power that was revealed in the second series of HDC conditioning tests, S/N 025A through S/N 028A, prompted an investigation to determine the cause for this difference in performance. This investigation effort included continued cell pair testing, examination of the electrodes, matrix and electrolyte used in the cells, and the analysis of all this data to establish the possible cause and to formulate corrective measures.

Testing of cell pairs S/N 026A and S/N 028A was done at the conditioning test levels consisting of inlet air conditioned to 294.2 K (70°F) dry bulb, dew point of 292.0 K (66°F) and a CO_2 partial pressure of 400 Pa (3 mmHg). The CO_2 removal efficiency of both units showed a gradual increase from the low sixties to an acceptable level in the mid-seventies. The voltage of both units leveled off at approximately 0.10 volts, as shown in figure 31, where the decay rate became less than 50μ volts/hr. Although the cell pairs demonstrated acceptable CO_2 removal and voltage decay rates, the absolute voltage levels were lower than those of the initial assemblies. The higher voltage level of the initial assemblies could not be reproduced in subsequent assemblies and when compared to previous TMA cells this higher voltage would be considered an exception. Cell pair S/N 026A continued on test for 75 days of continuous operation. The performance of this unit at 18 amperes leveled off at 0.11 volts and 70 percent CO_2 removal efficiency. Cell pair S/N 028A was restarted after 31 days of storage and operated for an additional 12 days. The performance of this unit at 18 amperes also leveled off at approximately 0.11 volts and 75 percent CO_2 removal efficiency.

The performance of cell pairs S/N 026A and S/N 028A improved with time to a CO_2 removal rate and voltage decay rate adequate for completion of the 90-day evaluation test. It appears that three of the four HDC cell pairs of this series, assembly #2, would have provided acceptable performance for system testing.

The analyses of the various parameters affecting HDC performance, utilizing the test data obtained through this investigation, revealed that the major contributor was the apparent change in the electrode catalyst. This is supported by the following discussion of test results.

The analysis of the electrolyte and matrix materials of the second series of HDC assemblies did not reveal any signs of contaminants. Comparison of the two batches of electrolyte used in assemblies #1 and #2, by means of potential sweeps and floating electrode tests gave identical results. It was, therefore, concluded that these two cell elements did not cause the change in the HDC performance.

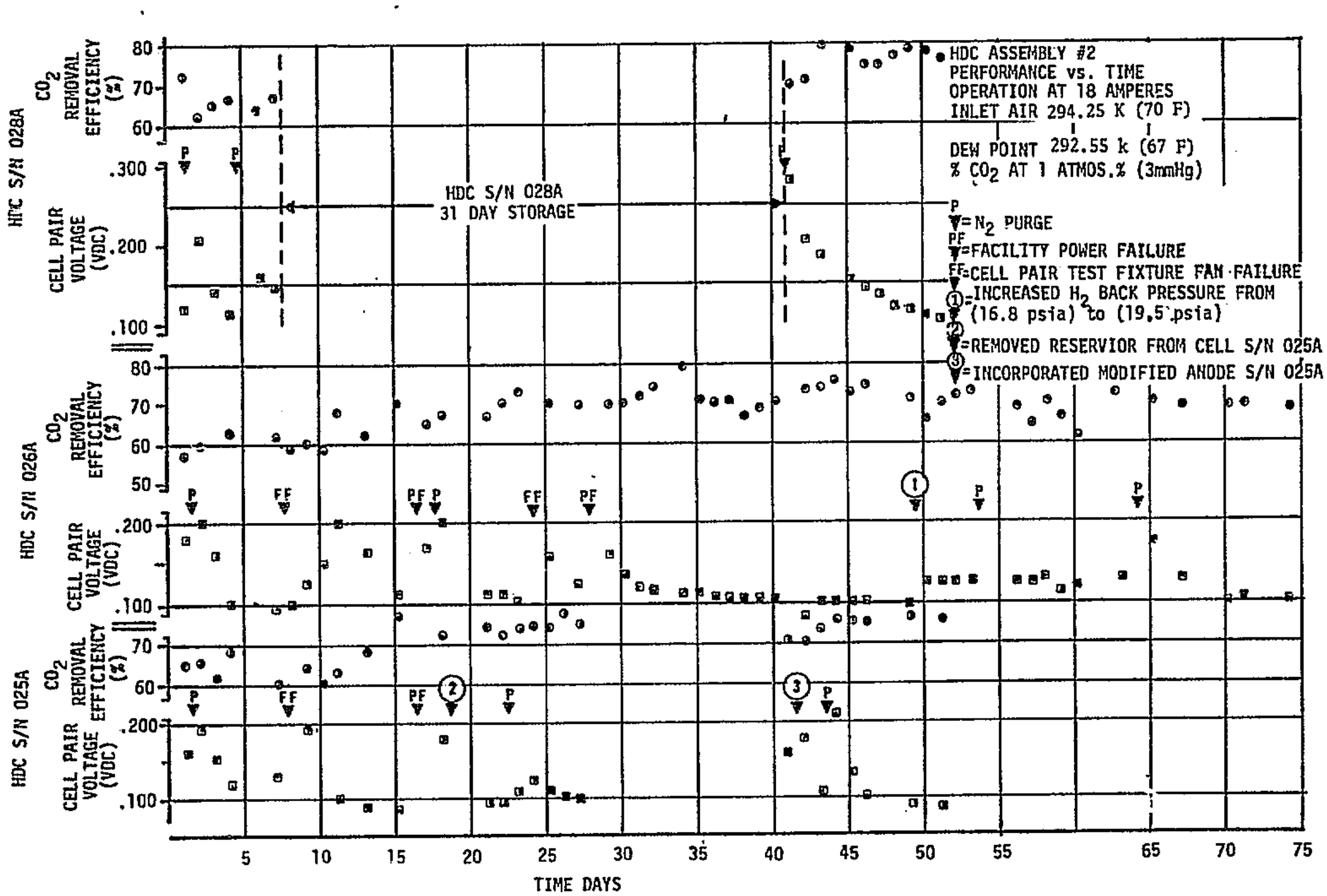

FIGURE 31 HDC CELL PAIR PERFORMANCE (HDC INVESTIGATION)

Micrographic examinations consisting of scanning electron microscope photographs (SEM), electron micrographs, microprobe and transmission of unused anode samples from cell assemblies #1 and #2 were made. The SEM examination showed a higher catalyst-teflon density in the center of the electrode cross-section than in the outside edge region, and this feature was somewhat more pronounced in the assembly #2 anode. Microprobe X-ray analysis for fluorine showed a high teflon concentration in the outer regions of both electrodes, which is an undesirable feature, but there was no apparent difference between the two samples in this respect. Transmission electron micrographs of 2000 angstrom thick cross-sections also did not reveal any significant difference in the structure of the two anode samples.

BET* surface area measurements of the anode samples of assemblies #1 and #2 gave 25.3 and 20.1 m^2/gram, respectively, and these results correlate with the BET surface area of the original platinum-blacks (29.2 and 25.0 m^2/gram). There was also a difference in bulk density between the two platinum-blacks (0.606 versus 0.733 g/cm^3).

These differences in the catalyst properties can have a significant effect on the electrode fabrication process and the resulting electrode structure. The structure of the electrode has an important bearing on electrolyte take-up rate and capacity, and the intra-electrode mass transport rate. Since the CO_2 transfer rate is controlled by mass transport within the catholyte, it is therefore sensitive to cathode structure and electrolyte take-up.

At the conclusion of this HDC performance investigation a meeting was held at NASA JSC to review the test data and the proposed recommendations for rebuilding the HDC cell pairs. The HDC cell pair fabrication and conditioning changes agreed upon at this meeting were (1) electrode fabrication to be done in a controlled temperature and dew point ambient environment, (2) increased catalyst mixing time, (3) pre-checking of the platinum-black for surface area and bulk density, (4) improved quality control during electrode fabrication, (5) performing of floating electrode tests on new electrodes prior to incorporation in cell pairs, (6) pre-checking the electrolyte for contaminants, (7) conditioning the cell parts at an inlet air temperature of 294. K (70 °F) and dew point of 290. K (64 °F), and (8) allowing conditioning tests to run up to three weeks to obtain steady state performance. These changes were incorporated in the HDC assembly #3.

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*A technique of measuring the surface area by gas absorption which was developed by Brummer, Emmet and Teller (BET).

System Testing

Testing of the One Man E/C ARS was done in three phases. The first phase lasted 50 calendar days with 900 hours of "on" time accumulated. The second phase was the 90-day system test with the third assembly series of HDC. Phase three was a continuation of the system test beyond the 90 days to verify performance at an inlet air P_{CO_2} of 400 Pa (3.0 mmHg).

Phase I

Phase I was the initial integration and check out of the system packages and test facility. During this phase numerous shutdowns were necessary for debugging the system, checking various operating modes and automatic shutdown procedures, and making modifications to the test facility.

The system shake down test was run at an air inlet temperature of 294 K (70°F), a CO_2 level of 0.33 percent (P_{CO_2} = 2.5 mmHg), and a relative humidity of 70 percent. The performance of the HDC and WVE cells is shown in figures 32 and 33, respectively. For the first six days the system was in operation for only eight hours per day. A failure in the test rig air conditioning after 10.5 days resulted in a relative humidity condition well below specifications, and a subsequent hydrogen leak in the seal area of one WVE cell pairs, S/N 003, developed. Upon examination it was determined that the hydrogen leak had occurred in this particular cell because of a relatively rough gold plating on the center housing. This was corrected by replating the housing and reassembling the cell with new matrix and electrolyte. Testing was resumed in three days without pre-conditioning the rebuilt cell. Shortly after, a step decrease in CO_2 removal efficiency was noted and the HDC cells were removed from the system one at a time to check the individual efficiencies in a separate chamber under identical conditions. During this time system operation continued with three HDC cell pairs. The system CO_2 removal efficiency ranged from 56 percent to 61 percent, while the separate, individual cell pairs revealed the following efficiencies:

S/N 025 - 48 percent

S/N 026 - 64 percent

S/N 027 - 65 percent

S/N 028 - 56 percent

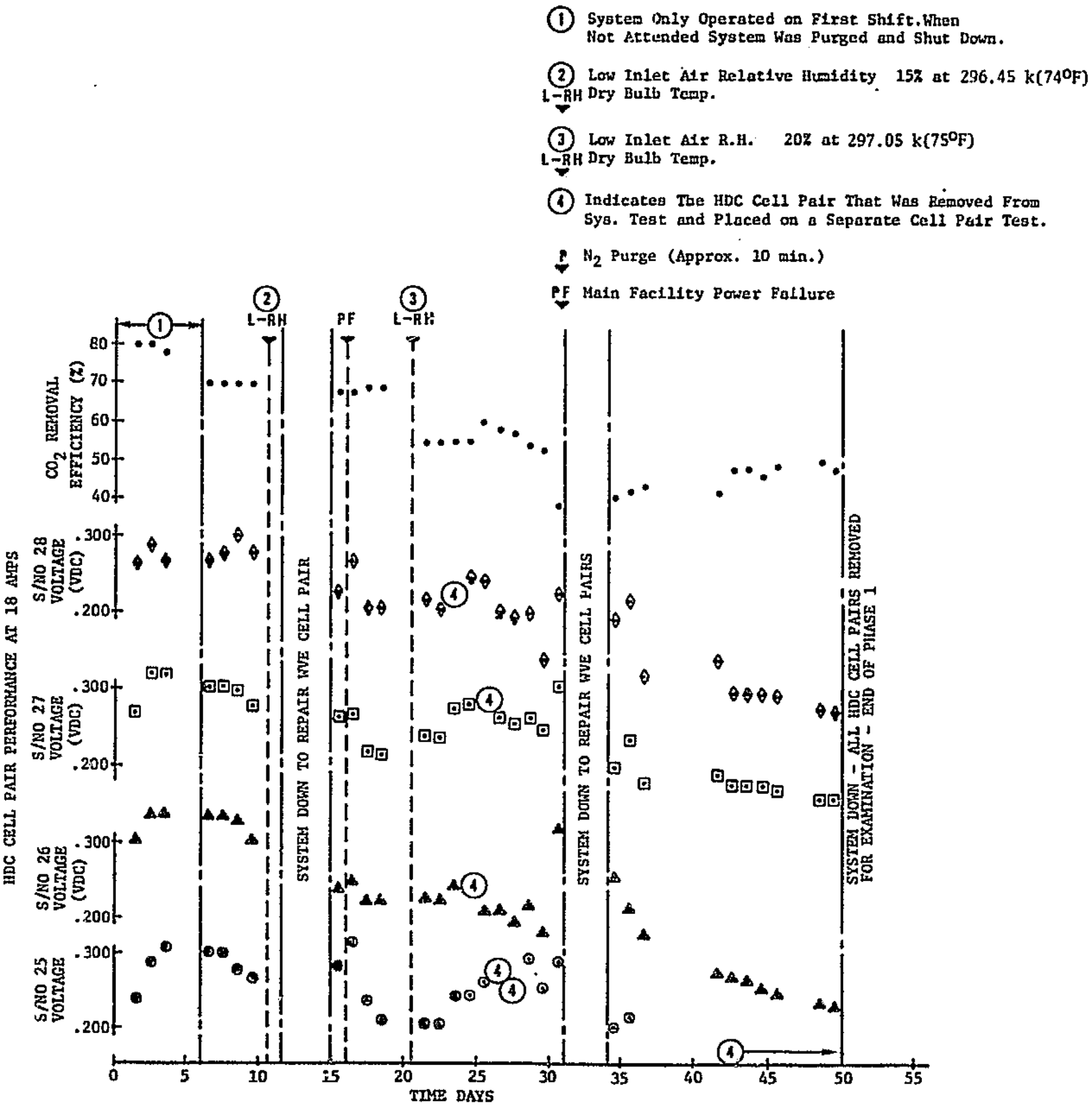

FIGURE 32 PHASE I SYSTEM PERFORMANCE (HDC)

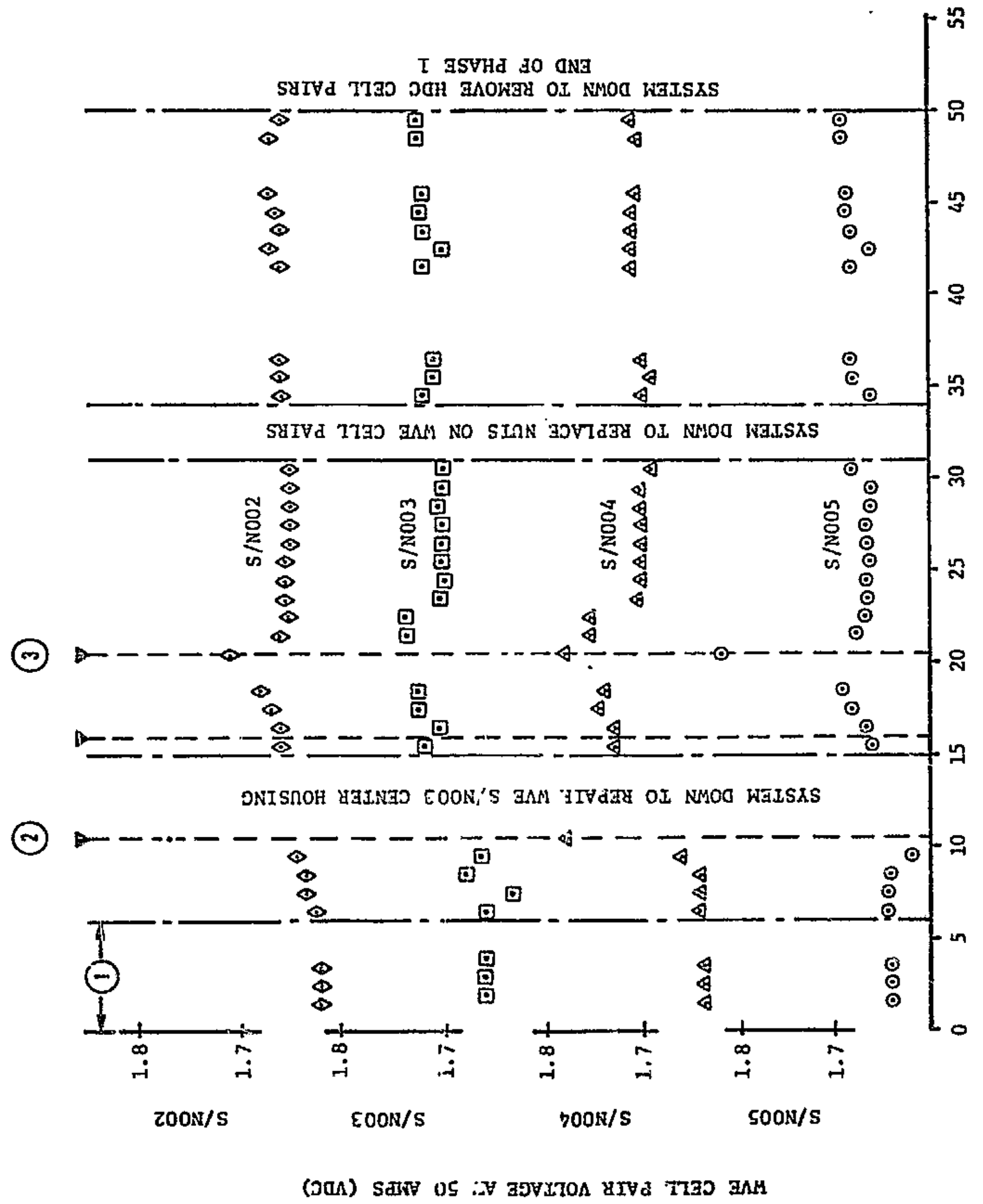

FIGURE 33 PHASE I SYSTEM PERFORMANCE (WVE)

By the end of the 28th test day, all the HDC's had been reinstalled in the system and the CO_2 transfer efficiency was 54 percent at an inlet relative humidity of 76 percent. The inlet air relative humidity was then increased in expectation that this would increase the cell efficiency. Within 24 hours after operating at 90.4 percent relative humidity a second step change in CO_2 removal efficiency, from 55 percent to 40 percent was noted, and after 48 hours, the system shut itself down automatically because of a hydrogen leakage in the WVE section. The investigation of this H_2 leakage and the two step changes in cell efficiency revealed the following:

1. The operation at 90.4 percent relative humidity caused the WVE cell pairs to flood since they had been conditioned at 87.4 percent relative humidity, in accordance with the test plan.

2. The flooding of the WVE's allowed excessive sulfuric acid electrolyte to contact the WVE housing bolts at the air exit side. The low resistance path offered by the acid film caused the metal-solution potential of the stainless steel nuts to go into the transpassive region ($>$1.2 volts) and rapid corrosion of the stainless steel nuts released the housing compression in the seal area allowing the hydrogen to leak.

3. Both step changes in cell efficiency occurred after a very possible contamination of the HDC's with acid from a flooded WVE; that is, after the rebuild of WVE cell pair S/N 003 without conditioning and after the 90.4 percent relative humidity operation.

4. It was reasoned at this time that H_2SO_4 from the WVE cell pairs may have "leaked" into the HDC cell pairs. This would be equivalent to the addition of an inert electrolyte to the HDC cell pairs, which was known from previous testing to result in reduced CO_2 transfer efficiencies.

The nuts on the WVE cell pairs were replaced with titanium nuts and the system tests were continued with a CO_2 transfer efficiency of 40 $\pm$ 3 percent. Testing was stopped after a total of 895 hours and the HDC cell pairs were disassembled for examination. This examination revealed massive contamination of the HDC cell pairs, as shown in figure 34, with acid and corrosion products. A qualitative analysis of the electrolyte from each HDC cell matrix showed large amounts of sulfate ion, which was not present in the original TMAC electrolyte, and considerable amounts of iron and nickel, the corrosion products of the stainless steel nuts of the WVE, were found also in the HDC matrix and on the cathode surface.

This evidence of a large contamination of the HDC cell pairs with acid explains the step change in CO_2 transfer and the slow voltage decay during the later testing in July.

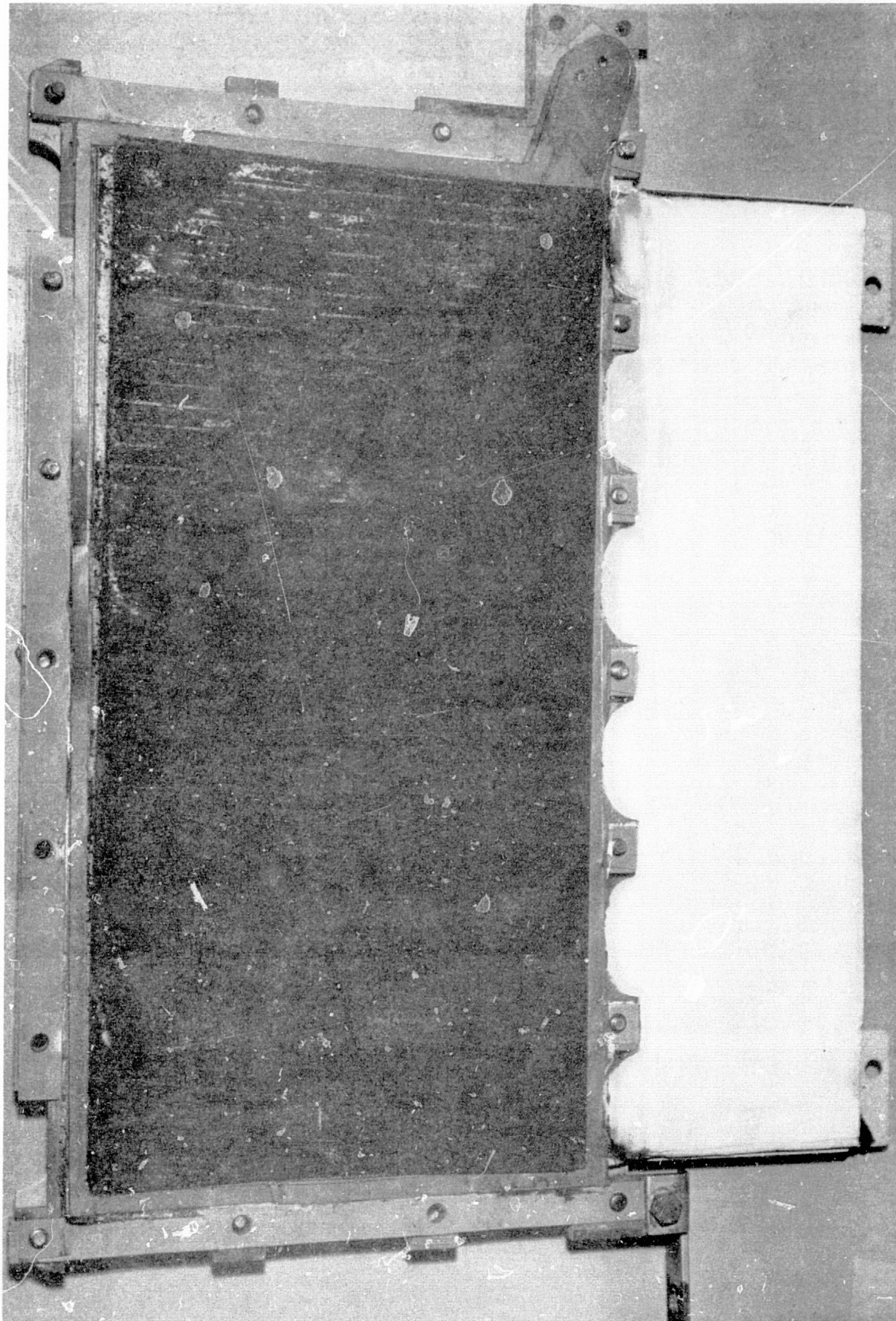

FIGURE 34 DISASSEMBLED PHASE I HDC CELL PAIR

Phases II & III

To prevent any future acid contamination of the HDC cells the following changes to the system were made:

1. All cell pairs were conditioned at a temperature delta (the difference in the inlet air temperature and dew point) of 2.8 K (5°F) and the system would not be operated at a ΔT of less than 3.3 K (6°F).

2. A drip tray was inserted between the last WVE cell pair and the first HDC cell pair in the cell pair rack.

3. A scrubber type filter containing LiOH was installed in the H_2 system at the inlet to the HDC cell pairs.

The WVE cell pairs remained in the cell pair package for approximately six months, while the HDC cell pairs were reassembled and successfully completed their conditioning tests.

After the completion of the HDC cell pair conditioning for the third series of HDC assemblies, the One Man E/C ARS was restarted for the Phase II 90-Day Test Program. The order of the cell pairs in the system rack was as follows:

Cell Pair S/N	Position From Top of Rack	H_2 Flow Position	
WVE 002	1 (Top)	All WVE	All Cell Pairs in Parallel Air Flow
003	2	Cell Pairs	
004	3	In Parallel	
005	4	H_2 Flow	
HDC 029	5	1st to Rec. H_2	
030	6	2nd	
031	7	3rd	
032	8 (Bottom)	Last to Rec. H_2	

The initial data plotted in figures 35 and 36 showed the performance of the HDC and WVE units to be acceptable but revealed a steep decrease in voltage of HDC S/N 032. Since this cell pair was positioned last to receive the H_2 flow, it was thought that the CO_2 level in the H_2 gas stream, which passed through this cell pair, could be affecting its performance. In order to investigate this theory more, cell pairs S/N 029 and S/N 032, the first and the last, were switched places within the cell pair rack of the system. This switched position of the cell pairs S/N 029 and S/N 032 and the reversal of the H_2 flow through the HDC cells both revealed that the cell to receive the H_2 last had a lower power output than it did when it was the first cell to receive H_2. This low performance can easily be restored to its original output by a short, 10 second N_2 purge. During this short purge cycle, the anode is brought up to the same potential as the cathode thereby oxidizing any poisons, such as "reduced CO_2" (vida infra), which have accumulated on the anode catalyst. Testing continued with the HDC cell pairs S/N 029 and S/N 032 in their switched positions for the 90-day test program and for the Phase III extended system test period.

In order to obtain meaningful data, it was necessary to reactivate the HDC anode via a 10 second nitrogen purge at the start of each new test condition. The HDC voltage was measured as a function of time after anode reactivation to provide a comparison of the data under equivalent conditions.

A plot of HDC cell voltage versus log time revealed two types of behavior as shown in figures 37 and 38, depending on current density and air inlet P_{CO_2}. Low current densities and high P_{CO_2} tended to favor a single straight line relationship over the whole 10,000 minute duration of the test (figure 37), whereas at high current densities and low P_{CO_2} gave a relationship typical of that shown in figure 38, a break in the slope followed by zero voltage decay. The initial dV/d (log t) slope was found to be independent of time, current density and P_{CO_2} level. No significant HDC performance difference could be detected between cells with PPF versus DS16-0 anodes even though the structure and catalyst loading of the two electrodes is vastly different. The straight line relationship between cell voltage and log time is compatible with catalyst poisoning via a dual-site adsorption mechanism such as would be expected from "reduced CO_2" (vida infra).

In acid solutions, CO_2 interacts with hydrogen adsorbed on platinum to form a strongly adsorbed species. This so-called "reduced CO_2" is difficult to oxidize and decreases the catalyst surface area available for hydrogen adsorption.* The rate and degree of poisoning by reduced CO_2 is dependent on the free CO_2 concentration in solution and is therefore very sensitive to anolyte pH. Above pH 9, the poisoning by reduced CO_2 is negligible. At potentials approaching 800 mV versus the hydrogen electrode in the same solution, reduced CO_2 is rapidly oxidized to CO_2 and this explains the effectiveness of a closed circuit nitrogen purge of the anode in restoring HDC cell power. It was also found

*J. Giner, Electrochim. Acta, 8, 857 (1963)
J. Giner, Ibid. 9, 63 (1964)
S. Schuldinger, et al, NRL 6388 (1966)

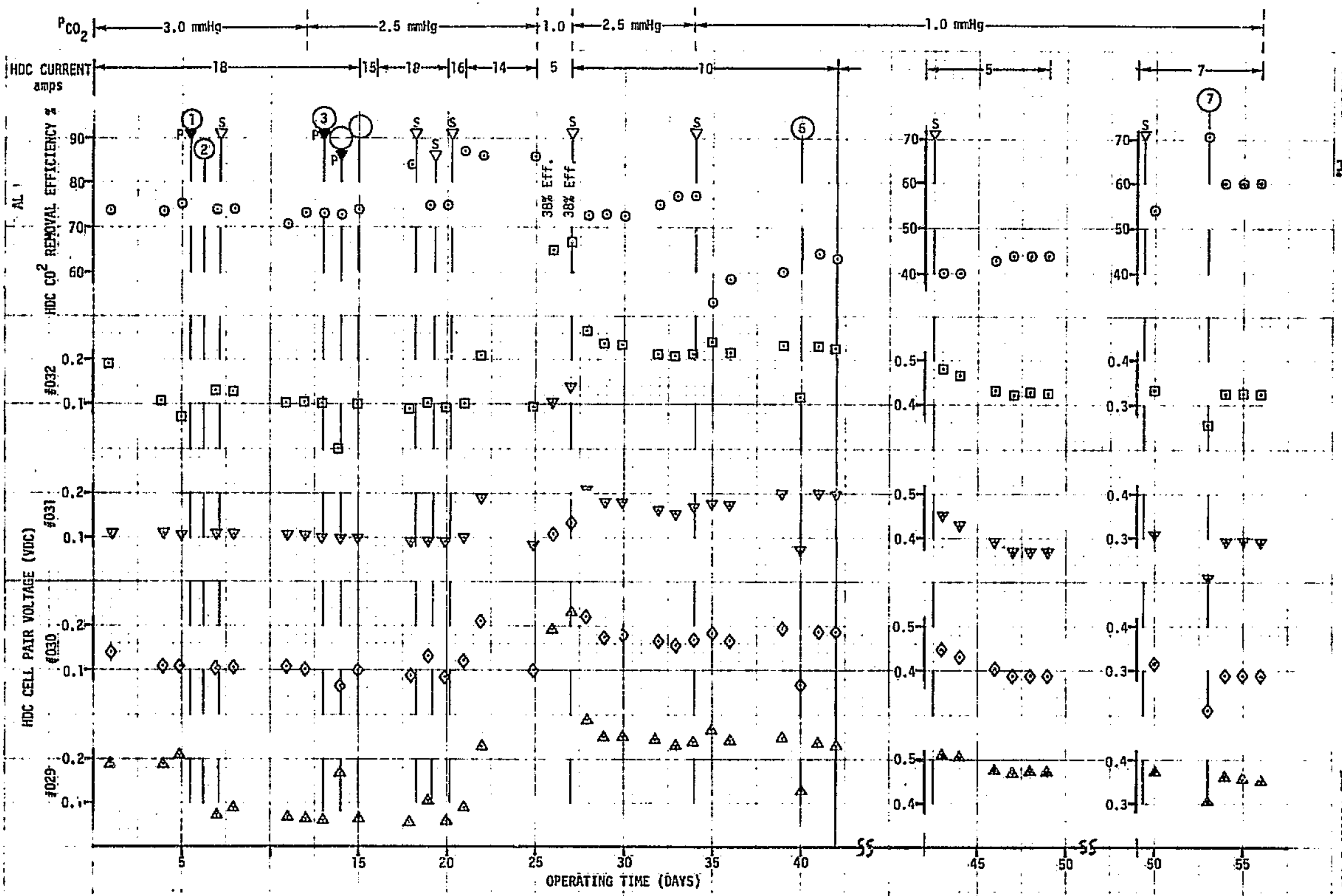

FIGURE 35 HDC CELL PAIR PERFORMANCE ON SYSTEM TEST

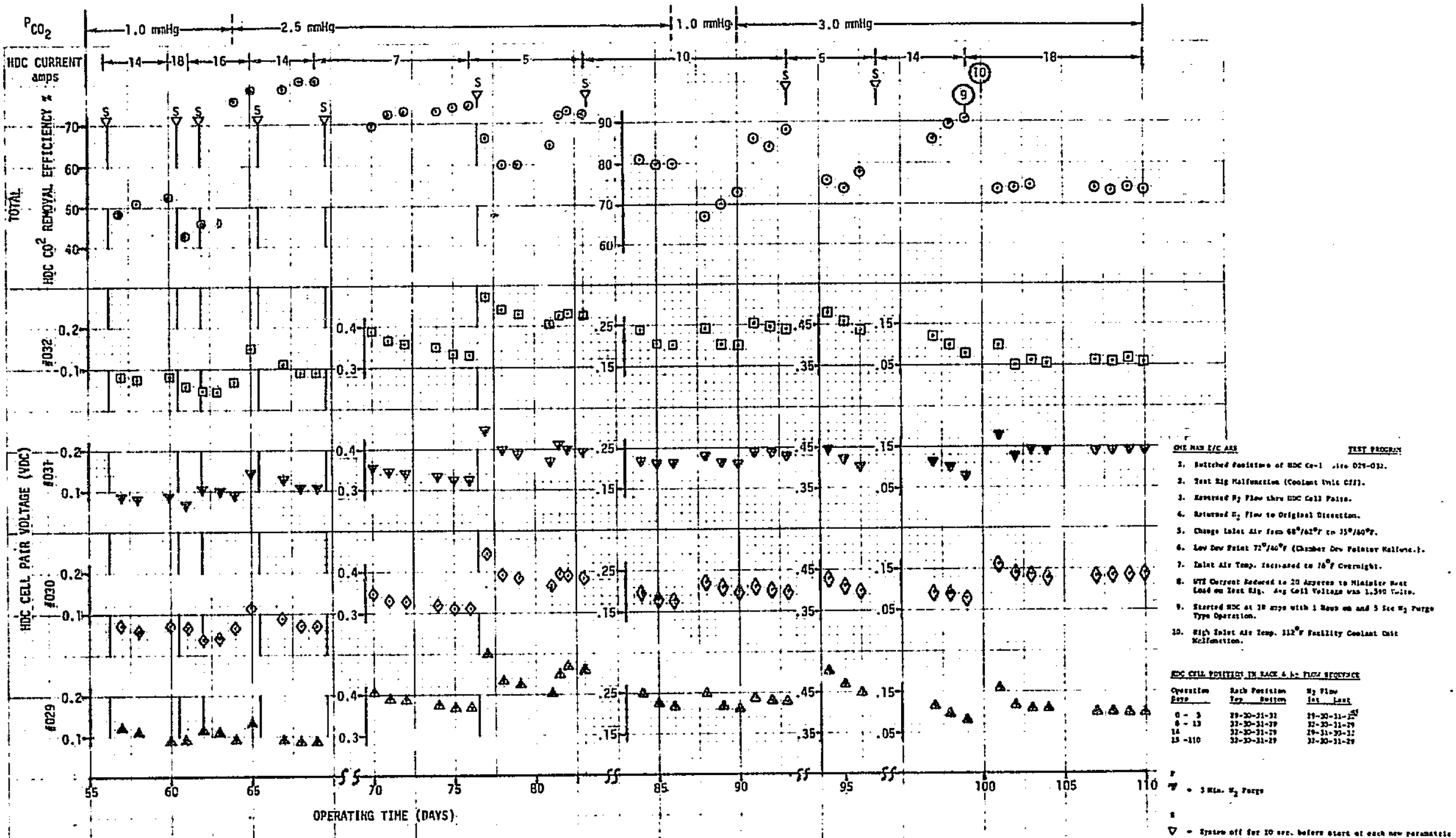

FIGURE 35 HDC CELL PAIR PERFORMANCE ON SYSTEM TEST (CONCLUDED)

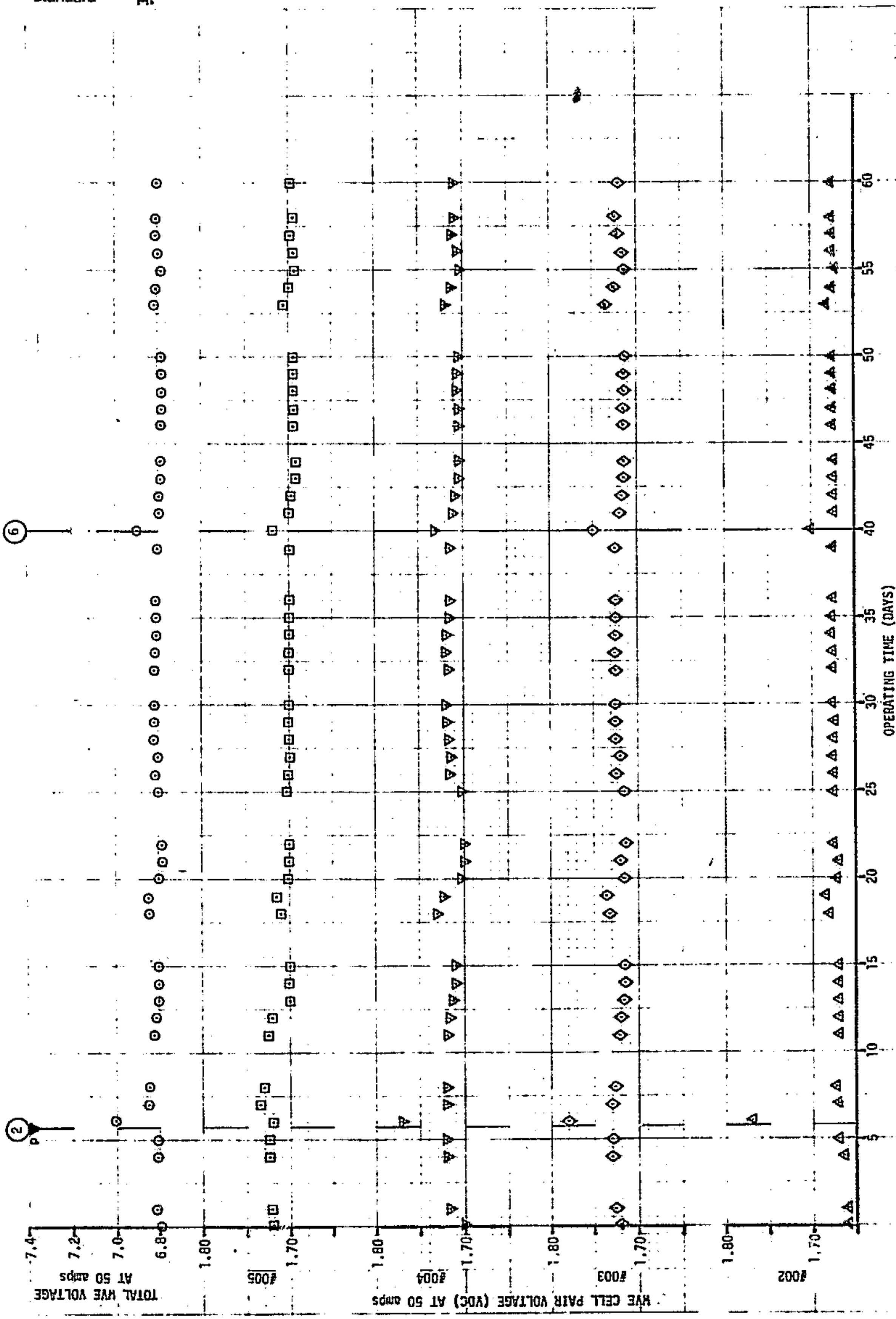

FIGURE 36 HVE CELL PAIR PERFORMANCE ON SYSTEM TEST

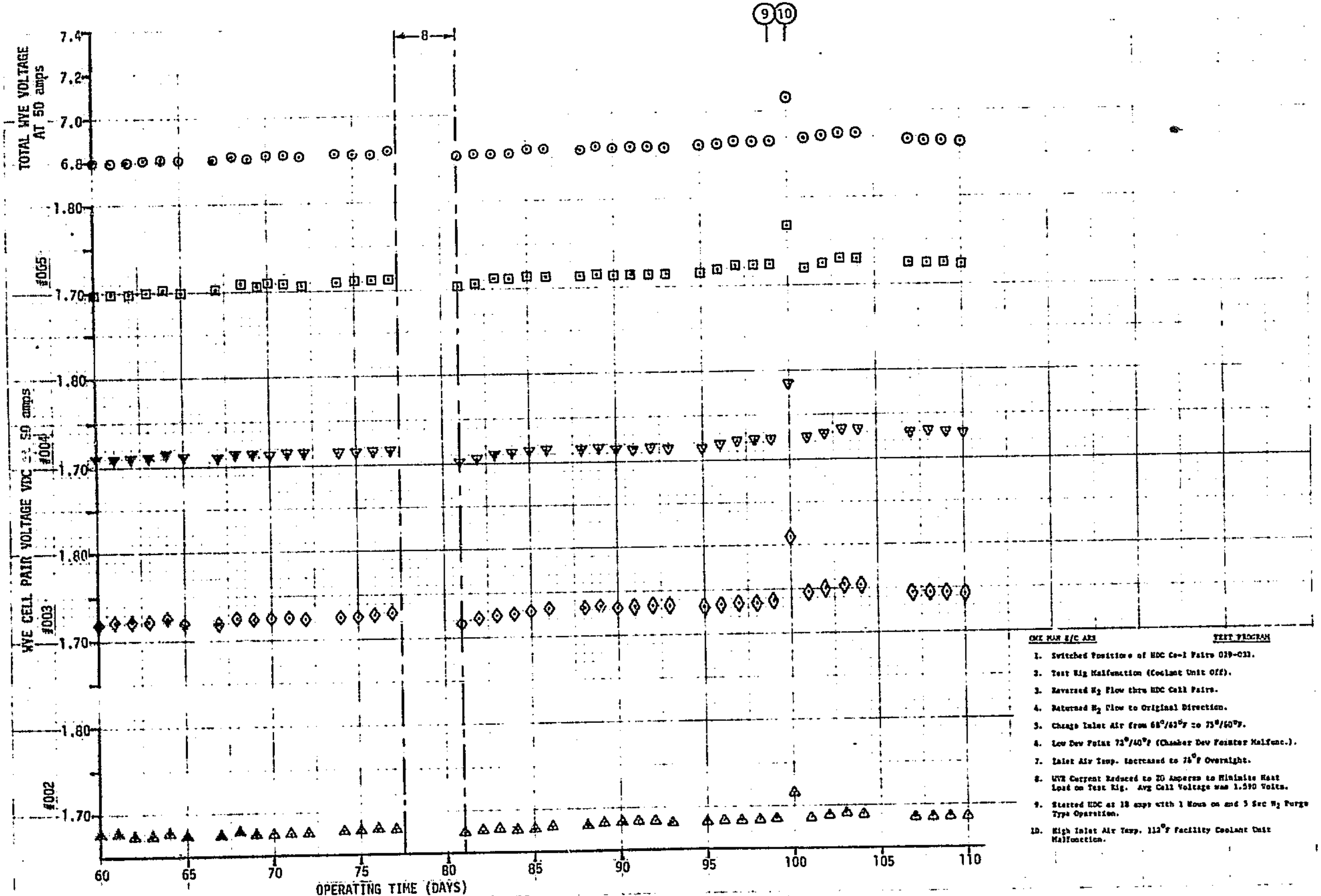

FIGURE 36 WVE CELL PAIR PERFORMANCE ON SYSTEM TEST (CONCLUDED)

that a very short (<10 second) nitrogen purge is sufficient to restore power fully if the cell is maintained at the operating current during the purge. Under these conditions the anode is driven to high potentials more rapidly. Thus, the HDC anode can be reactivated in a very short time if it is forced into a potential region where reduced CO_2 is readily oxidized. An open circuit nitrogen purge would have no effect except for relaxation of the cell concentration gradient and electroosmostic pumping force.

It now is believed that there is sufficient evidence to conclude definitely that "reduced CO_2" poisoning is the major cause of the short-term HDC power decay. The long-term decay rate (at an operating current of 10 amperes) determined from the data in figures 37 and 38 is less than 10μ V/hr, which is excellent.

The current (log i) - voltage curve shown in figure 39 supports a poisoning mechanism for HDC power decay in that the exchange current decreases with time while the Tafel slope remains constant. It was also found that both the Tafel slope and the exchange current are independent of air P_{CO_2} level over the 133 to 400 Pa (1 to 3 mmHg) range. One unusual feature is the steepness of the Tafel slope. This is the reason for the low HDC cell output power at the normal operating current of 18 amperes. A complete analysis of the various cell polarizations would be necessary in order to find ways of decreasing the Tafel slope and increasing cell power output.

The 90 day test program and the Phase III extended tests provided HDC parametric data, HDC short term voltage decay slopes, and long term performance varrations on the WVE and HDC units.

The CO_2 removal rate and transfer efficiency versus current density at three P_{CO_2} levels is shown in figures 40 and 41, respectively. The current density for maximum efficiency increases with increasing P_{CO_2} level. Operation at current densities above the point of maximum efficiency gives an increase in the absolute amount of CO_2 processed but at a great expenditure of WVE power for oxygen production as discussed on page 37. There was no evidence of a change in CO_2 processing rate with time and the one man CO_2 removal requirements of 1 kg/day (2.2 lbs/day) can be met by operating at 16 amperes at an air inlet P_{CO_2} of 400 Pa (3 mmHg).

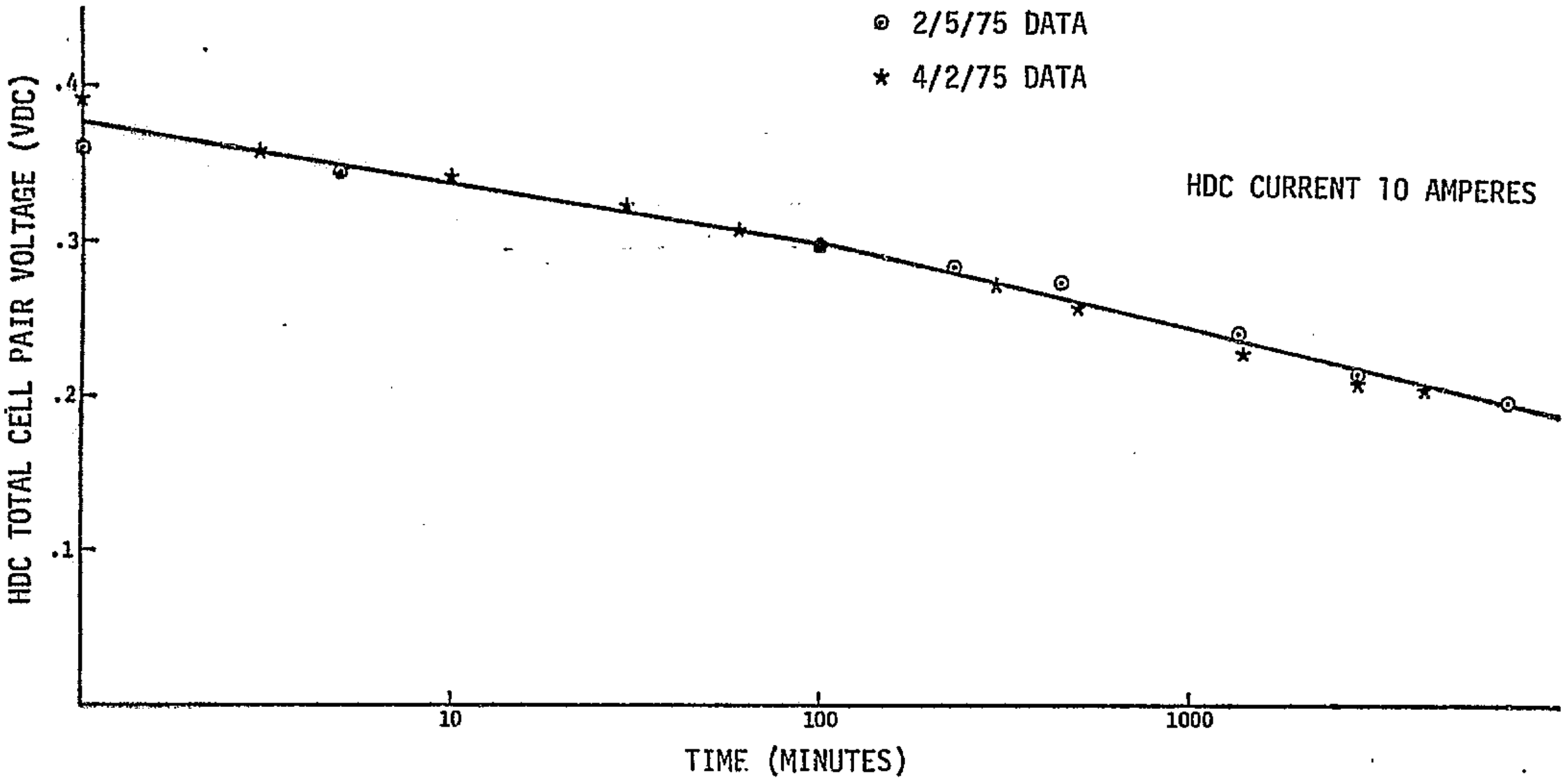

FIGURE 37 PHASE II HDC PERFORMANCE AT 2.5 mmHg P_{CO_2}

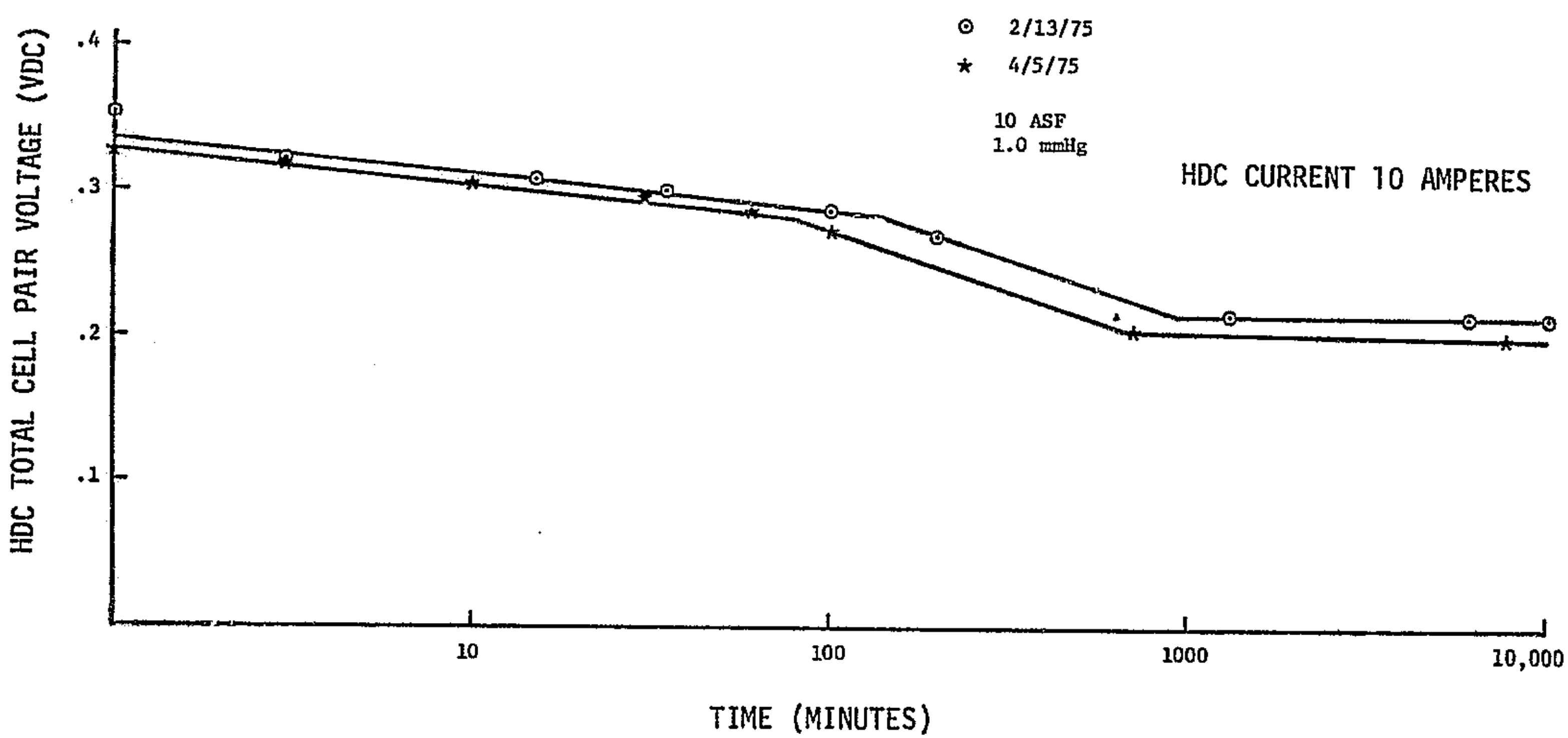

FIGURE 38 PHASE II HDC PERFORMANCE AT 1.0 mmHg P_{CO_2}

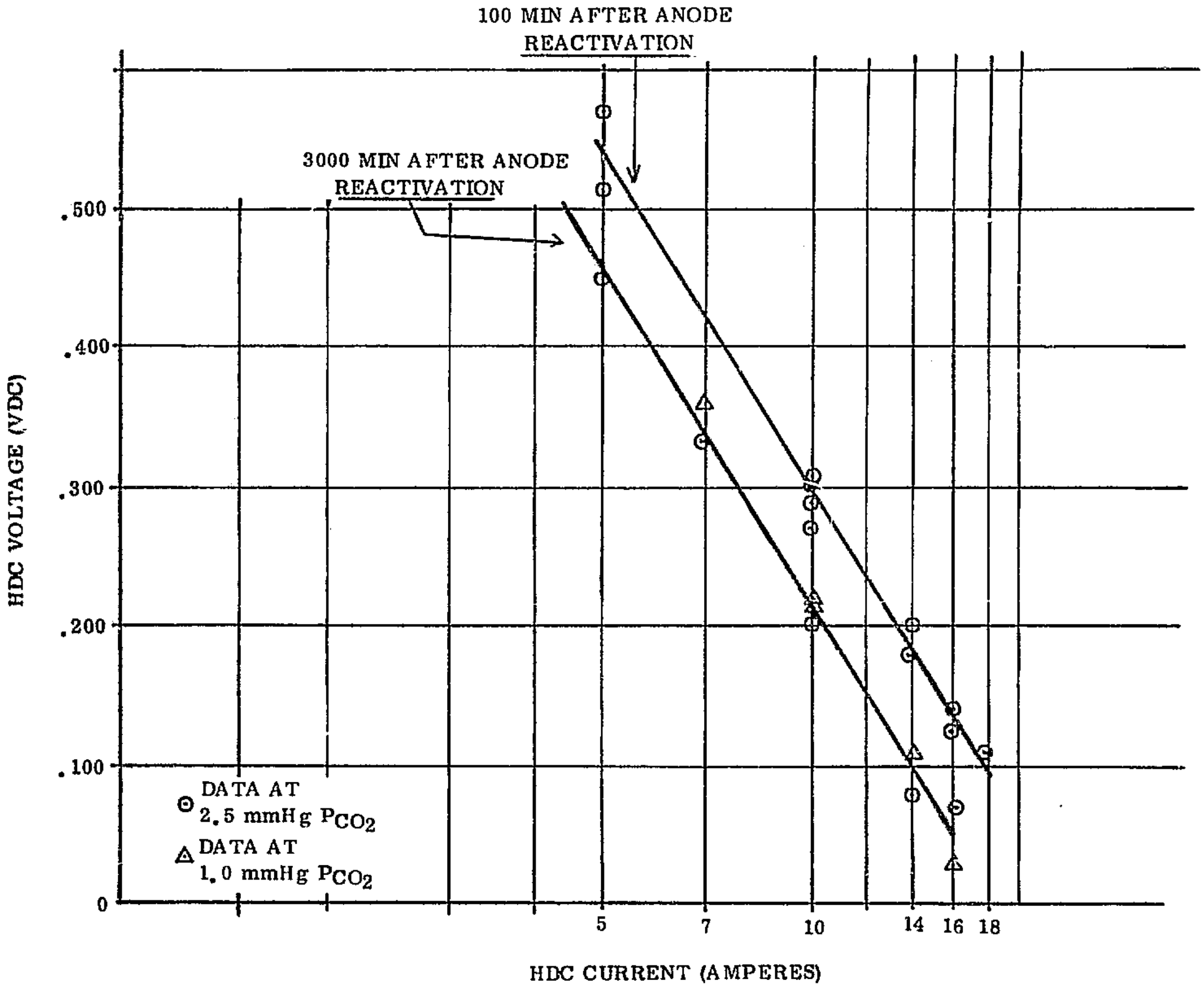

FIGURE 39 HDC VOLTAGE VERSUS CURRENT AT 1 mmHg PCO_2

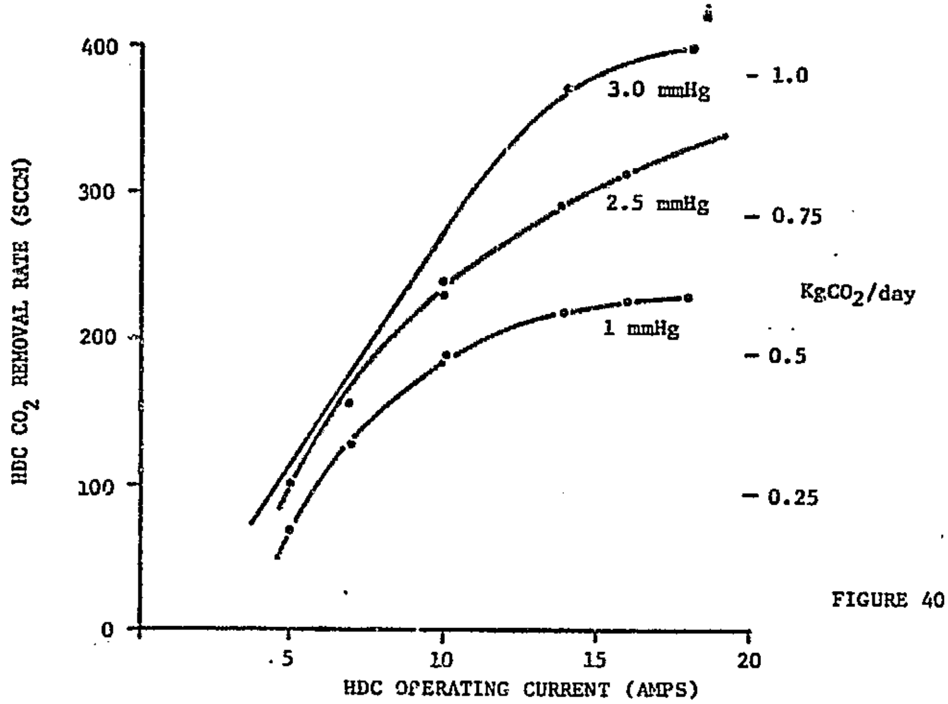

FIGURE 40 HDC CO_2 REMOVAL RATE VERSUS OPERATING CURRENT

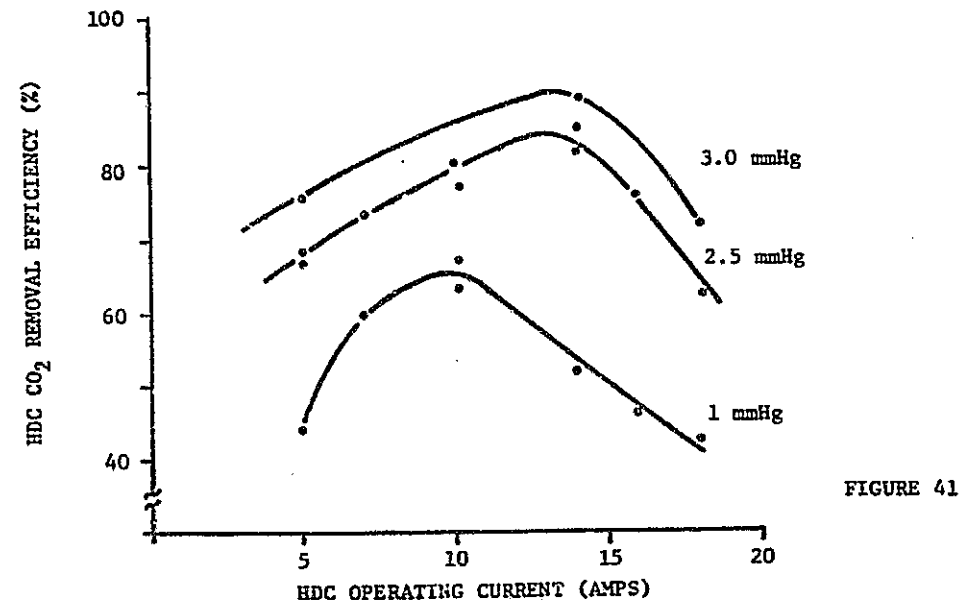

FIGURE 41 HDC CO_2 REMOVAL EFFICIENCY VERSUS OPERATING CURRENT

HDC ELECTROLYTE PROPERTIES

The physical properties of TMA bicarbonate and hydroxide were determined for use in the NASA JSC math model of the HDC and for more complete comparison of the TMA versus Cs_2CO_3 electrolytes of the HDC. The following properties of TMA bicarbonate and hydroxide were determined, as presented in Tables IV through VIII and figures 42 through 45.

- Water Vapor Pressure versus Temperature & Concentration
- Conductivity versus Temperature & Concentration
- Density versus Concentration
- Viscosity versus Concentration

The density measurements were made with a 25 ml pycnometer calibrated with distilled water. Weighing was accurate to ± 0.01 grams and the temperature was controlled to ± 0.1 K. The data should be accurate to four significant figures.

Viscosity measurements were made with an Ostwald Viscometer calibrated with distilled water. An average of ten time readings (± 0.01 second) was taken for each point and the temperature was controlled to ± 0.5 K. The data is accurate to three significant figures.

A potentiostat operating at a constant voltage (100 ± 0.5 mV peak to peak) square wave of 1 k Hz was used to determine electrolyte conductivity. The resistance was determined by measuring the current extrapolated to zero time (± 2 μ seconds) in relation to the voltage pulse, in order to eliminate electrode polarization effects. The current was measured to three significant figures and the solution temperature controlled to ± 0.25 K. The data should be accurate to three significant figures.

The electrolyte water vapor pressure was measured with a calibrated Cambridge Dew Pointer, accurate to ± 0.25 K, in a closed loop circulating system with solution temperature control to ± 0.05 K. Dew point measurements were made at a minimum of six solution temperatures between 278.15 K and 308.15 K (5 and 35°C) for each concentration. The data from the best line fit of the dew point versus temperature plot were cross-plotted as P/P^0 (relative humidity) versus mole fraction H_2O and log P/P^0 versus 1/T to determine the numbers presented in the vapor pressure tables. The relative accuracy is estimated to be better than 0.5 percent.

TABLE IV WATER VAPOR PRESSURE IN kPa AND (mmHg) OF TMA BICARBONATE VERSUS CONCENTRATION AND TEMPERATURE (P_{CO_2} = 101 kPa or 1 atm)

Wt % \ K (°F)	283.15 (50)	285.95 (55)	288.75 (60)	291.45 (65)	294.25 (70)	297.05 (75)	299.85 (80)	302.55 (85)	305.35 (90)
0	1.228 (9.21)	1.476 (11.07)	1.766 (13.25)	2.106 (15.80)	2.502 (18.77)	2.963 (22.23)	3.495 (26.22)	4.108 (30.82)	4.808 (36.07)
15	1.205 (9.04)	1.444 (10.83)	1.728 (12.96)	2.055 (15.42)	2.426 (18.20)	2.879 (21.60)	3.400 (25.51)	3.992 (29.95)	4.666 (35.00)
20	1.182 (8.87)	1.412 (10.59)	1.686 (12.65)	2.000 (15.00)	2.381 (17.86)	2.809 (21.07)	3.302 (24.77)	3.868 (29.02)	4.492 (33.70)
25	1.152 (8.64)	1.376 (10.32)	1.640 (12.30)	1.944 (14.58)	2.294 (17.21)	2.709 (20.32)	3.173 (23.80)	3.706 (27.80)	4.324 (32.44)
30	1.117 (8.38)	1.330 (9.98)	1.586 (11.90)	1.877 (14.08)	2.203 (16.53)	2.595 (19.47)	3.053 (22.90)	3.542 (26.57)	4.122 (30.92)
35	1.072 (8.045	1.274 (9.56)	1.508 (11.31)	1.780 (13.35)	2.093 (15.70)	2.450 (18.38)	2.866 (21.50)	3.338 (25.04)	3.878 (29.09)
40	1.016 (7.62)	1.200 (9.005)	1.421 (10.66)	1.681 (12.61)	1.974 (14.81)	2.309 (17.32)	2.709 (20.32)	3.146 (23.60)	3.671 (27.54)
45	0.922 (6.92)	1.097 (8.23)	1.302 (9.77)	1.537 (11.53)	1.817 (13.63)	2.129 (15.97)	2.487 (18.66)	2.905 (21.79)	3.400 (25.51)
50	0.852 (6.39	1.016 (7.62)	1.204 (9.03)	1.421 (10.66)	1.673 (12.55)	1.962 (14.72)	2.295 (17.22)	2.677 (20.08)	3.111 (23.34)
55	0.758 (5.685)	0.900 (6.749)	1.064 (7.98)	1.265 (9.49)	1.486 (11.15)	1.748 (13.11)	2.049 (15.37)	2.382 (17.87)	2.786 (20.90)
60	0.649 (4.87)	0.776 (5.82)	0.921 (6.91)	1.088 (8.16)	1.284 (9.63)	1.508 (11.31)	1.766 (13.25)	2.070 (15.53)	2.419 (18.15)

C-2

TABLE V SPECIFIC CONDUCTIVITY (ohm cm)$^{-1}$ OF TMA BICARBONATE
(P_{CO_2} = 101 kPa or 1 atm)

Wt % \ K (°F)	283.15 (50)	285.95 (55)	288.75 (60)	291.45 (65)	294.25 (70)	297.05 (75)	299.85 (80)	302.55 (85)	305.35 (90)
5	0.0178	0.0182	0.0196	0.0205	0.0214	0.0223	0.0232	0.0241	0.0250
10	0.0277	0.0298	0.0319	0.0341	0.0364	0.0385	0.0407	0.0428	0.0450
15	0.0357	0.0385	0.0414	0.0442	0.0471	0.0499	0.0528	0.0557	0.0585
20	0.0418	0.0449	0.0482	0.0515	0.0547	0.0580	0.0612	0.0644	0.0677
25	0.0465	0.0498	0.0531	0.0566	0.0600	0.0633	0.0668	0.0704	0.0742
30	0.0496	0.0530	0.0566	0.0600	0.0635	0.0669	0.0703	0.0744	0.0788
35	0.0517	0.0551	0.0586	0.0622	0.0657	0.0692	0.0727	0.0768	0.0809
40	0.0505	0.0539	0.0574	0.0607	0.0641	0.0675	0.0712	0.0753	0.0800
45	0.0443	0.0476	0.0509	0.0541	0.0576	0.0610	0.0645	0.0682	0.0719
50	0.0364	0.0394	0.0424	0.0455	0.0485	0.0516	0.0549	0.0586	0.0623
55	0.0292	0.0319	0.0346	0.0374	0.0401	0.0429	0.0461	0.0493	0.0530
60	0.0227	0.0251	0.0277	0.0301	0.0326	0.0351	0.0377	0.0405	0.0435

TABLE VI WATER VAPOR PRESSURE IN kPa AND (mmHg) OF TMA HYDROXIDE VERSUS CONCENTRATION AND TEMPFRATURE

Wt % \ K (°F)	283.15 (50)	285.95 (55)	288.75 (60)	291.45 (65)	294.25 (70)	297.05 (75)	299.85 (80)	302.55 (85)	305.34 (90)	Relative Humidity
0	1.228 (9.209)	1.472 (11.069	1.767 (13.252)	2.107 (15.805)	2.503 (18.778)	2.963 (22.228)	3.495 (26.220)	4.109 (30.824)	4.814 (36.113)	100
5	1.194 (8.96)	1.436 (10.77)	1.718 (12.89)	2.050 (15.38)	2.435 (18.27)	2.883 (21.63)	3.401 (25.51)	3.998 (29.99)	4.684 (35.14)	97.3
10	1.149 (8.62)	1.381 (10.36)	1.653 (12.40)	1.972 (14.79)	2.343 (17.58)	2.774 (20.81)	3.271 (24.54)	3.846 (28.85)	4.506 (33.80)	93.6
15	1.090 (8.18)	1.312 (9.84)	1.570 (11.78)	1.872 (14.04)	2.225 (16.69)	2.633 (19.75)	3.106 (23.30)	3.651 (27.39)	4.278 (32.09)	88.8
20	1.009 (7.57)	1.213 (9.10)	1.452 (10.89)	1.732 (12.99)	2.058 (15.44)	2.435 (18.27)	2.873 (21.55)	3.378 (25.34)	3.958 (29.69)	82.2
25	0.898 (6.74)	1.080 (8.10)	1.293 (9.70)	1.542 (11.57)	1.833 (13.75)	2.169 (16.27)	2.558 (19.19)	3.007 (22.56)	3.524 (26.44)	73.2
30	0.768 (5.76)	0.922 (6.92)	1.104 (8.28)	1.317 (9.88)	1.565 (11.74)	1.852 (13.89)	2.185 (16.39)	2.569 (19.27)	3.009 (22.57)	62.5
35	0.621 (4.66)	0.746 (5.60)	0.894 (6.71)	1.066 (8.00)	1.266 (9.50)	1.500 (11.25)	1.769 (13.27)	2.079 (15.60)	2.435 (18.27)	50.6

TABLE VII SPECIFIC CONDUCTIVITY $(\text{ohm cm})^{-1}$ OF TMA HYDROXIDE

Wt % \ K (°F)	283.15 (50)	285.95 (55)	288.75 (60)	291.45 (65)	294.25 (70)	297.05 (75)	299.85 (80)	302.55 (85)	305.35 (90)
5	0.0840	0.0885	0.0929	0.0973	0.1017	0.1061	0.1104	0.1148	0.1192
10	0.1428	0.1511	0.1592	0.1675	0.1755	0.1838	0.1919	0.2002	0.2083
15	0.1780	0.1881	0.1985	0.2088	0.2190	0.2293	0.2396	0.2499	0.2602
20	0.1993	0.2092	0.2191	0.2288	0.2387	0.2487	0.2586	0.2686	0.2795
25	0.2048	0.2145	0.2243	0.2341	0.2438	0.2335	0.2634	0.2733	0.2831
30	0.1758	0.1860	0.1961	0.2061	0.2161	0.2261	0.2361	0.2461	0.2561
35	0.1370	0.1471	0.1571	0.1674	0.1778	0.1880	0.1981	0.2082	0.2184

TABLE VIII TETRAMETHYLAMMONIUM HYDROXIDE

Concentration	Density at 297.15 K (24°C)	Abs. Viscosity	Kin. Viscosity
Wt %	Grams/cc	Centipoise	Centistokes
35	1.0348	8.28	8.00
30	1.0281	4.69	4.56
25	1.0220	3.27	3.20
20	1.0163	2.46	2.42
15	1.0112	1.92	1.90
10	1.0067	1.55	1.54
5	1.0030	1.24	1.24

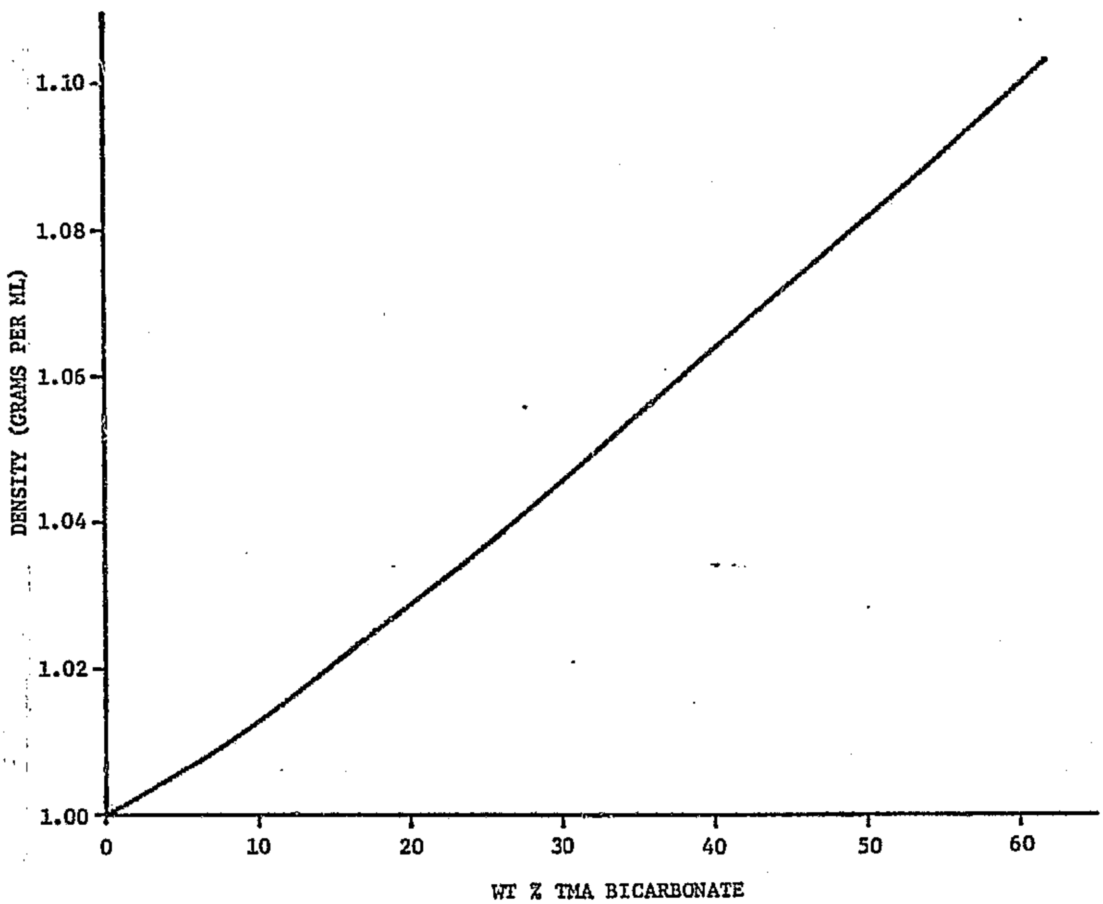

FIGURE 42 TETRAMETHYLAMMONIUM BICARBONATE SOLUTION DENSITY VS CONCENTRATION AT 297.15 K (24°C)

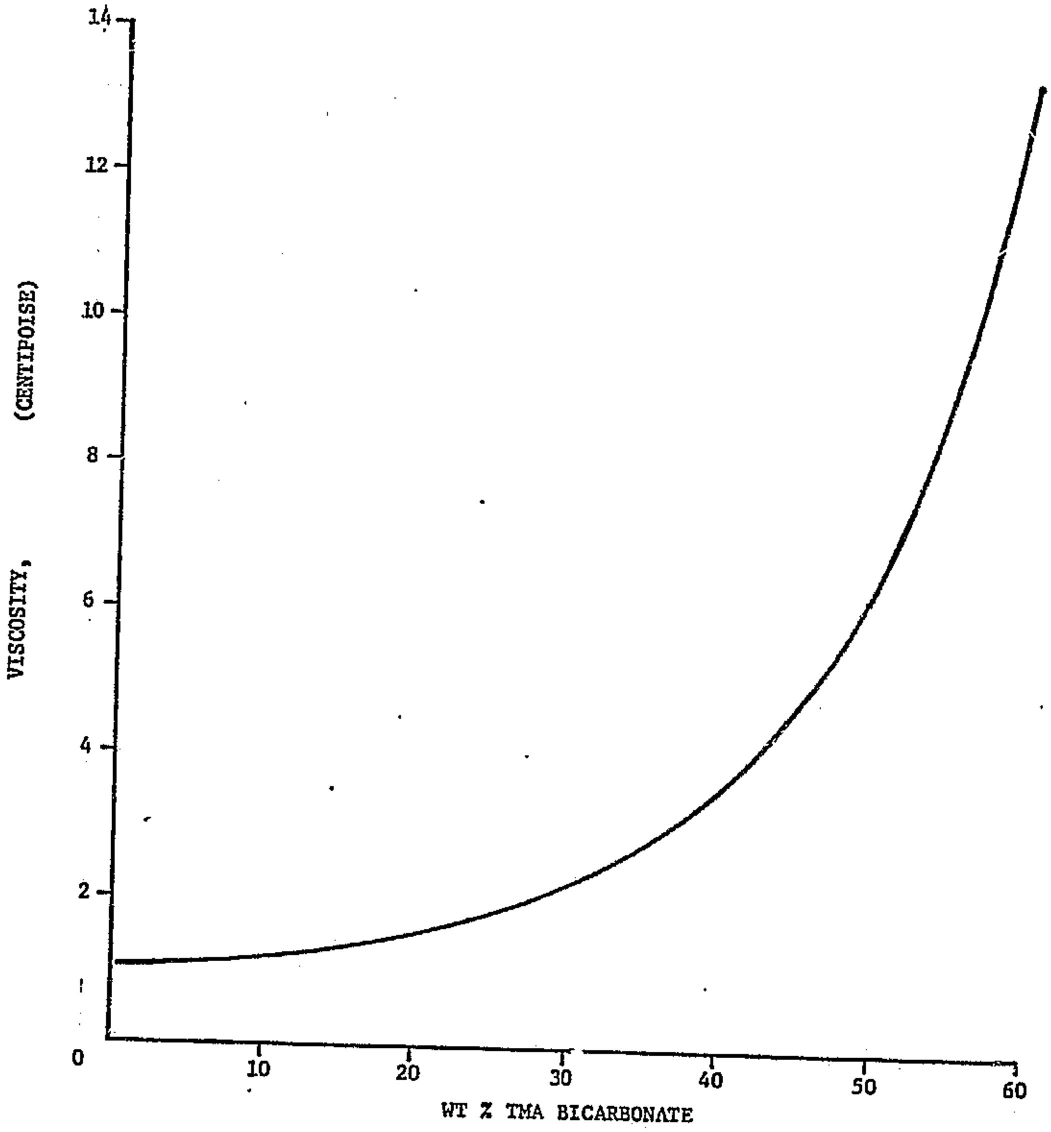

FIGURE 43 TETRAMETHYLAMMONIUM BICARBONATE SOLUTION VISCOSITY VS CONCENTRATION AT 297.15K (@24°C)

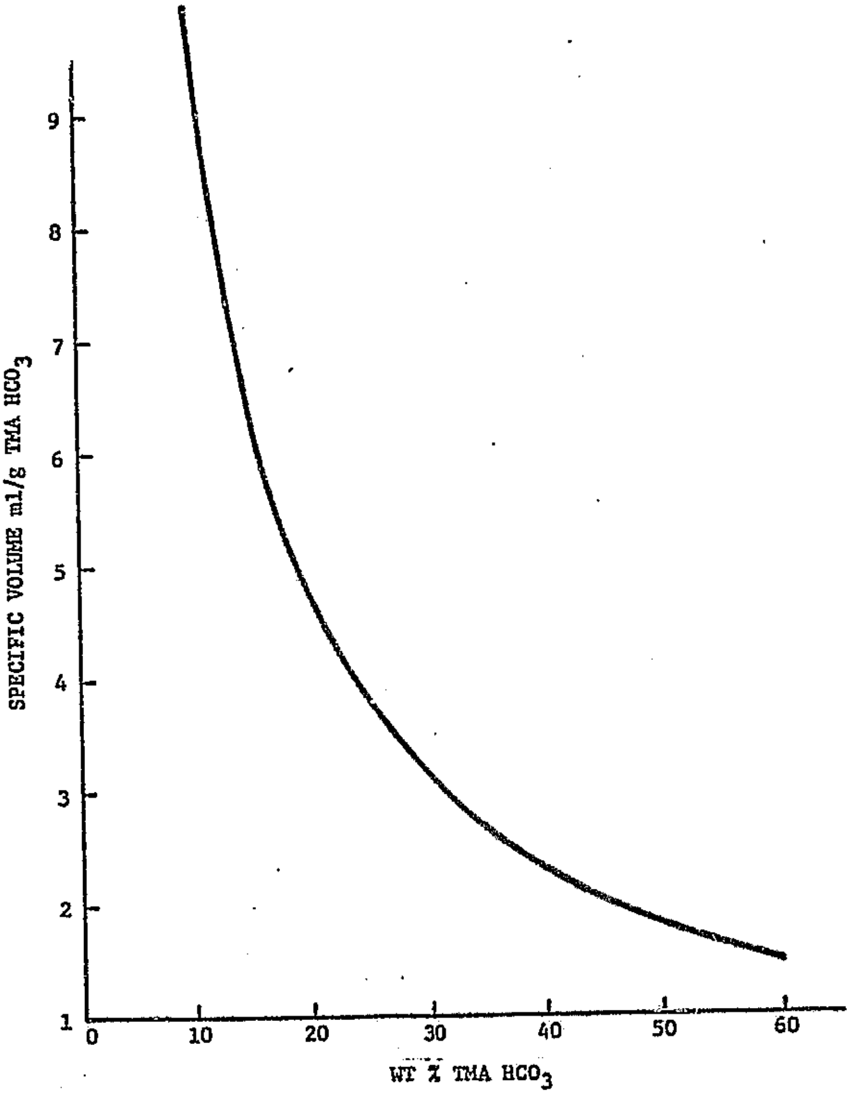

FIGURE 44 TETRAMETHYLAMMONIUM BICARBONATE SPECIFIC VOLUME VERSUS WEIGHT PERCENT AT 297.15K (24°C)

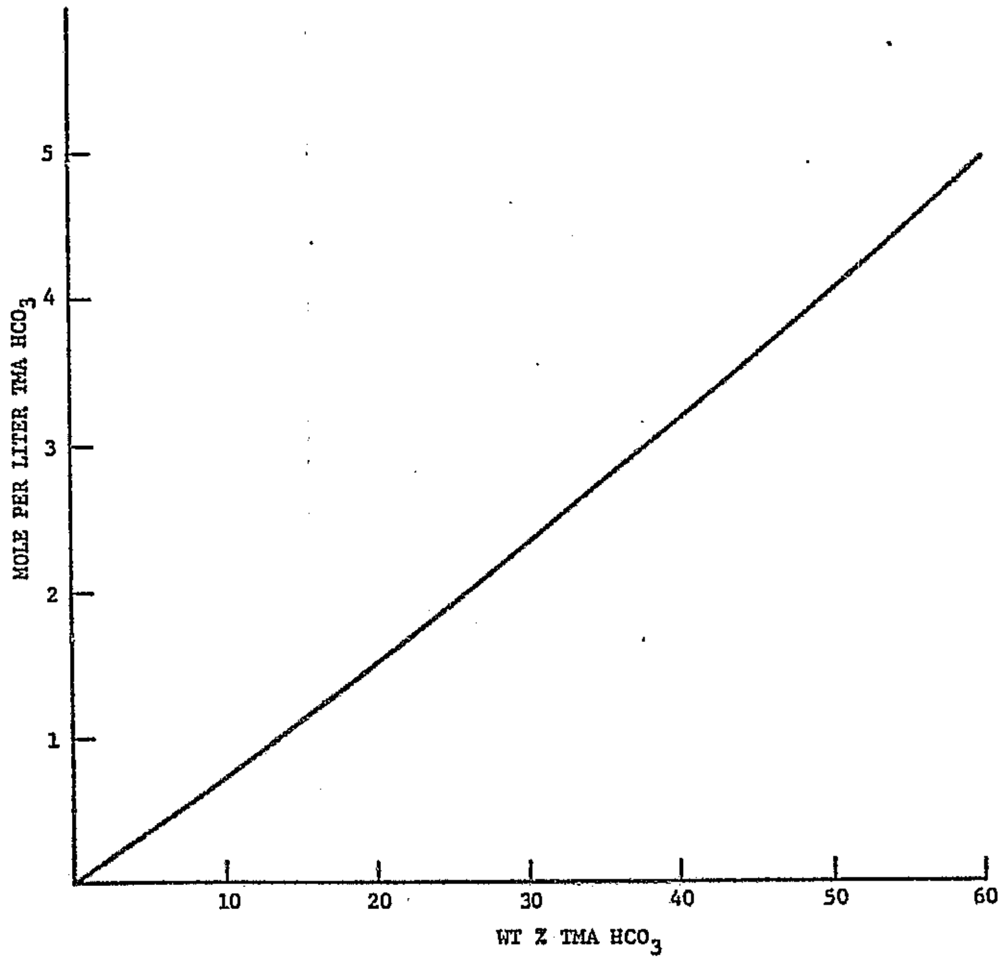

FIGURE 45 TETRAMETHYLAMMONIUM BICARBONATE MOLES PER LITER VERSUS CONCENTRATION AT 297.15K (24°C)

PREPARATION FOR DELIVERY

Prior to preparing the system for shipment a "Familiarization and Operations Manual" was prepared. This manual provides instructions for preparing the One Man E/C ARS for testing, and operating the system under its various operating modes. The manual also provides a description of the system, the system's function and how the system operates.

The refurbishment of the system after testing consisted of the following repair and clean-up tasks necessary to have the unit pass the Hamilton Standard inspection.

Cell Pair Package:

1. Repainted base frame. Paint had been scraped off the frame as the result of sliding the package in and out of the test chamber.

2. Replaced part of the panel decal. During the initial check out of the package it was necessary to remove a flow sensor which is mounted on the back side of the panel. This removal required the decal to be removed to allow access to the sensor mounting bolts.

3. Calibration check of the two sensors, pressure gauges and dial thermometers.

4. Cleaning of the cell pair electrical contact areas.

5. Setting the package up for storage and shipment, as defined in the Operations Manual.

Instrumentation/Control Package:

1. Calibration of all the voltage and ampere meter gauges.

2. Recheck of the combustible gas sensor/controller.

3. Setting the package up for storage and shipment, per the configuration as defined in the Operations Manual.

The shipment of the One Man E/C ARS also included a set of microfilmed drawings of the two packages. These drawings include parts lists, detail manufacturing drawings of make items and assembly drawings of both packages.

RELIABILITY/QUALITY ASSURANCE/SAFETY SUMMARY

The following is a summary of the effort performed during the various tasks of this program in the areas of Reliability, Quality Assurance and Safety.

- The successful demonstration of the One Man E/C ARS to operate over 110 days without a system malfunction verified that the system design is safe, durable and reliable.

- The automatic shutdown feature of the system provides the detection of facility or system malfunctions and the systematic shutdown of the system for all its modes of operation. The malfunction which caused the system to shut down is noted by the system status indicator lights which provides a quick detection of the problem. This shutdown and fault detection feature protects the system and environment from potential hazards associated with the WVE-HDC operation.

- Electrode fabrication procedures were changed to assure consistent high quality electrodes. These changes were a controlled ambient temperature and dew point during fabrication, longer and consistent mixing time of the catalyst, better procurement definitions and controls on the raw material, and Hamilton Standard Engineering surveillance of the electrode fabrication at P&WA.

- All the test facility and system malfunctions which occurred during Phase I of the test program were resolved and corrective action instituted to prevent the recurrence of each malfunction. As a result of this positive failure analysis, the test facility and system became more reliable.

APPENDIX A TEST PLAN

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

ECS-730029-L-009
Revision A, March 12, 1974
Revision B, Feb. 14, 1975

MASTER TEST PLAN

ONE-MAN ELECTROCHEMICAL AIR REVITALIZATION SYSTEM

PREPARED UNDER CONTRACT NAS 9-13679

by

HAMILTON STANDARD

DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JOHNSON SPACE CENTER

HOUSTON, TEXAS

JANUARY 1974

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J. C. Huddleston
Program Engineer

Approved by: Fred H. Greenwood
F. H. Greenwood
Program Manager

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TEST PLAN PROCEDURES		2
SECTION I	WVE CELL PAIR CONDITIONING	8
SECTION II	HDC CELL PAIR CONDITIONING	11
SECTION III	ONE-MAN E/C ARS TESTING	14

1.0 GENERAL INFORMATION

1.1 Scope

The purpose of this Master Test Plan is to define the test methods and equipment which will be utilized to perform the various Water Vapor Electrolysis (WVE) and Hydrogen Depolarized CO_2 Concentrator (HDC) cell pair, and integrated WVE/HDC System tests required under NASA/JSC Contract NAS 9-13679. This test program will be conducted at Hamilton Standard, Space Systems Department, test facilities.

1.2 Applicable Documents

NASA/JSC Contract NAS 9-13679

Hamilton Standard Program Plan for Contract NAS 9-13679.

One-Man E/C ARS Cell Pair Package - SVSK 88484

One-Man E/C ARS Instrument & Control Package - SVSK 88485

Electrochemical Cell Pair Assembly - SVSK 88486

1.3 Functional Requirements

Unless otherwise specified, the following operating conditions and requirements will apply to the testing of the WVE and HDC cell pairs as separate units.

Range of Inlet Air Conditions:

Air flow through cell pair	10-25 scfm
Inlet air dry bulb temperature	65^o to 75^oF
Inlet air relative humidity	35% to 90%
Inlet Air CO_2 partial pressure	1/4 to 3 mmHg
Oxygen concentration	20-21%

A

1.3 Functional Requirements - Continued

WVE operating requirements:

Nominal current density	50 asf
Maximum voltage	2.0 vdc
H_2 production	Current x 7.48 scc/min
O_2 production	Current x 3.74 scc/min

A

HDC operating requirements:

Nominal current density	18 asf
Min. H_2 inflow	350 scc/min
Current efficiency (design goal) @ 18 asf & 2.5 mmHg	CO_2 removed (scc/min) 7.5 x current (amps)

1.4 Test Condition Tolerances

Unless otherwise specified, the following tolerances will apply to the referenced test parameters:

Temperature	$\pm$ 1°F
Pressure	$\pm$ .1 psia $\pm$ .02 inches of water
Dew Point	$\pm$ 1°F
Voltage	$\pm$ 0.01 volts
Current	$\pm$ 0.10 amps
CO_2 Level	$\pm$ 2%
Flow Measurement	$\pm$ 2.8%

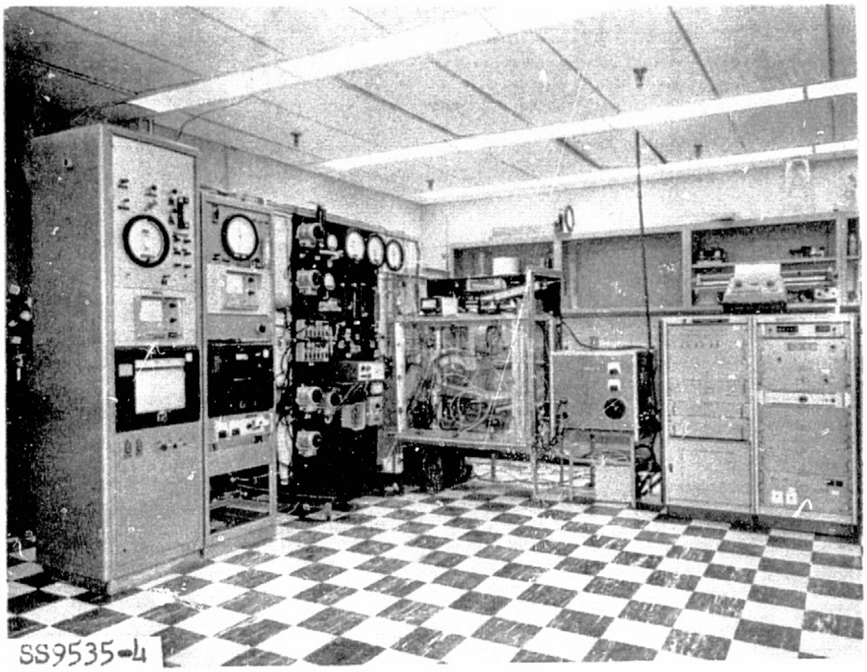
2.0 TEST PLAN AND PROCEDURES

The test plans and procedures for the following tests are detailed in the corresponding sections as noted:

Test	Section
WVE Conditioning Test	I
HDC Conditioning Test	II
One-Man E/C ARS Testing	III

2.1 Test Facility and Instrument Readings

The Hamilton Standard, Space Systems Department electrochemical test facility, where the test program will be conducted, is illustrated in the photographs of figure 1. The schematics of the test set-up for the various cell pair and system tests are defined in figures 2 and 3. The general data acquisition for all the testing is presented in Table 1.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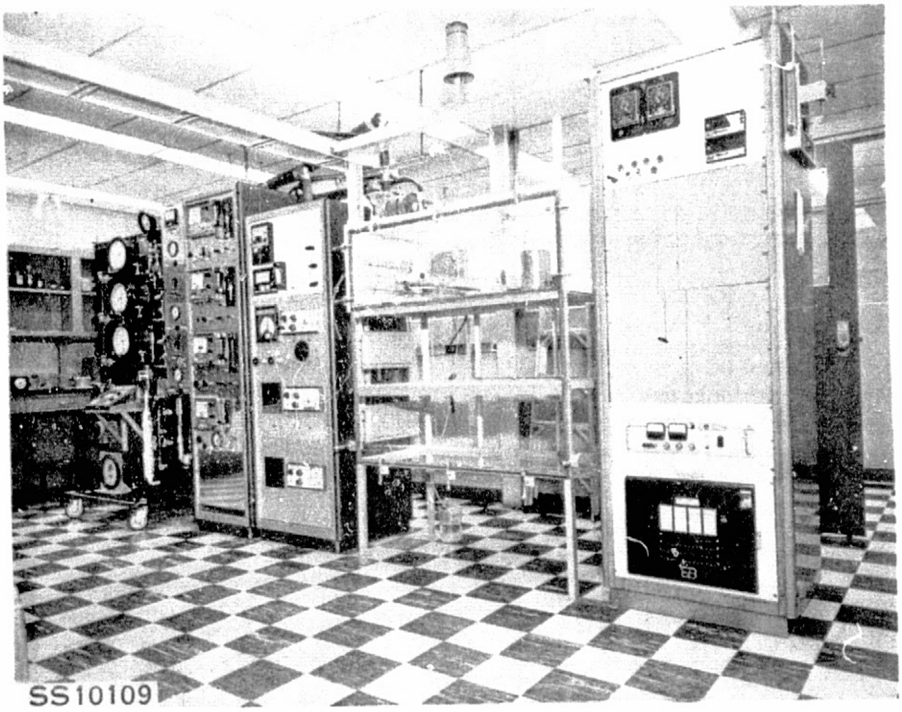
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FIGURE 1 ELECTROCHEMICAL TEST FACILITIES

A ONE-MAN E/C ARS TEST FACILITY

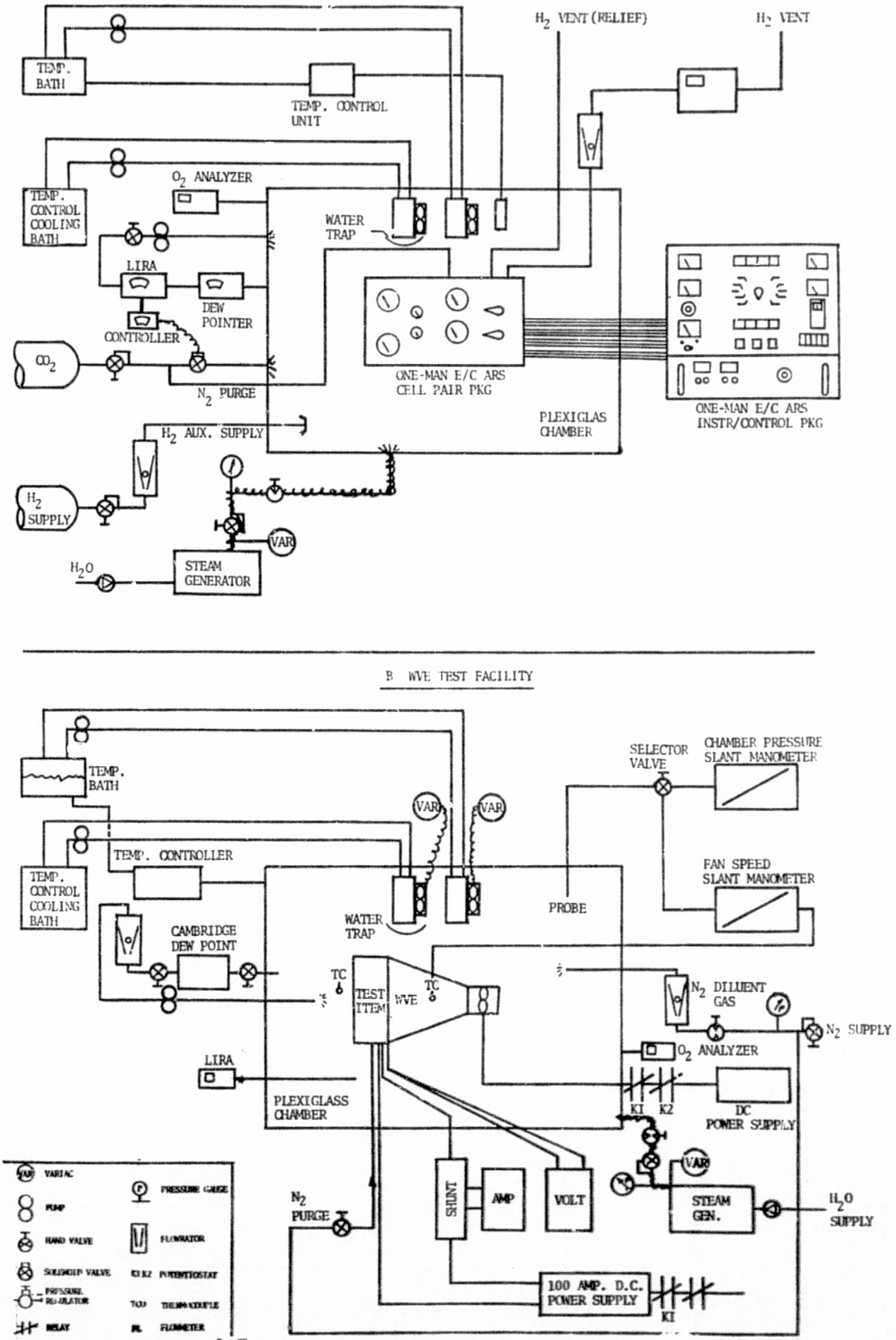

FIGURE 2 WVE & ONE-MAN E/C ARS TEST FACILITY

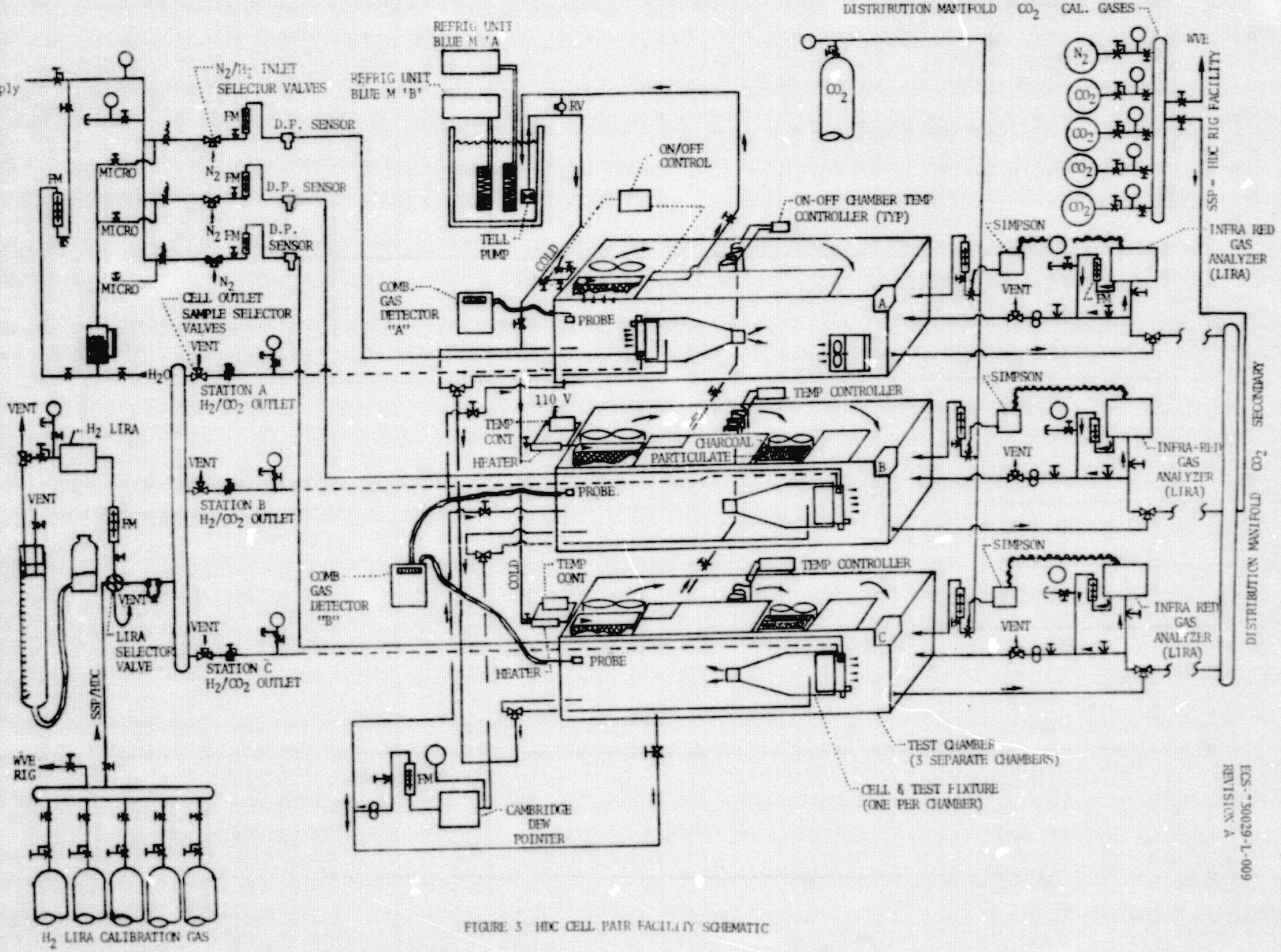

FIGURE 3 HDC CELL PAIR FACILITY SCHEMATIC

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DATA ACQUISITION- TABLE I

Data Point	Instrument	Range & Readout
Inlet & Outlet Air Temperature of Cell Pair (^oF)	Thermocouple and Bristol Recorder	0^o to 250^o (1^oF inc.)
Inlet Air Dew Point of Cell Pair (^oF)	Cambridge 880 Dew Pointer	-40^o to 120^oF (2^oF inc.)
HDC Hydrogen Inlet Temperature (^oF)	Thermocouple & Bristol Recorder	-30^oF to 250^oF (1^oF inc.)
Item Fan ΔP (inches of H_2O)	Slant Water Manometer	0 to 4 in. of H_2O (0.01 inc.)
WVE Hydrogen Outlet Pressure (psia)	HEISE Pressure Gauge	0 to 30 psia (0.1 psia inc.)
HDC Hydrogen Inlet Pressure (psia)	HEISE Pressure Gauge	0 to 30 psia (0.1 psia inc.)
HDC H_2/CO_2 Outlet Pressure (psia)	HEISE Pressure Gauge	0 to 30 psia (0.1 psia inc.)
Cell Pair Voltage (volts)	Digital Meter	0 to 4.0 volts (.0005 volts inc.)
Cell Pair Current (amps)	Digital Meter	0 to 100 amps (0.05 amp inc.)
HDC CO_2 Inlet Concentration (%)	Lira Gas Analyzer	0% to 1% (0.02% inc.)
HDC - CO_2 Outlet Concentration in H_2 Stream (%)	Lira Gas Analyzer	0% to 100% (2% inc.)
WVE Outlet Hydrogen Flow (cc/min.)	Water Displacement Measurement	1.0 cc inc. and 0.001 min. inc.
HDC - H_2/CO_2 Outlet Flow (cc/min.)	Water Displacement Measurement	1.0 cc inc. and 0.001 min. inc.
HDC - Hydrogen Inlet Flow (%)	Flowmeter	0% to 100% (2% inc.)
Chamber Gas O_2 Concentration (%)	Beckman O_2 Analyzer	0 to 100% (2% inc.)

SECTION I

WVE CELL PAIR CONDITIONING TEST PLAN

WVE CONDITIONING

This Test Plan describes the method used to condition the WVE cell pair assembly prior to its incorporation in the One-Man E/C ARS.

Test Facilities

Reference figures 1 and 2.

Test Procedure

Each unit will be inserted into the cell pair test fixture and installed in the test chamber. Set and maintain the inlet air and unit at the conditions as outlined below. Data will be taken daily and presented on log sheets per figure 4.

Parameter	Set Condition
Air Flow	10 scfm
Inlet Air Temperature	70°F
Inlet Air Dew Point Temperature	66°F
Chamber O_2 Concentration	20%
Current Density	50 asf
H_2 Back Pressure	1 psig

A

Test Duration

Approximately one (1) week. This is the time required for the cell to obtain stable operation at the defined test conditions. (1)

Special Instructions

During the initial days of conditioning, excess electrolyte will flow from the outlet air holes of the unit. This electrolyte should be drained from the cell and test fixture to prevent damage of the blower.

Acceptance Criteria

a) Voltage at 50 asf shall not exceed 1.7 volts.

b) The current (starting at 50 asf) for the last 24 hours of testing shall not drop more than 0.01 amps when operated at constant voltage. A

---

(1) Stable operation is considered when the unit's voltage and current do not change significantly with time.

WVE CONDITIONING

This Test Plan describes the method used to condition the WVE cell pair assembly prior to its incorporation in the One-Man E/C ARS.

Test Facilities

Reference figures 1 and 2.

Test Procedure

Each unit will be inserted into the cell pair test fixture and installed in the test chamber. Set and maintain the inlet air and unit at the standard conditions as outlined in paragraph 1.3. The exception is the inlet air dew point which will be held at 66°F. Data will be taken daily and presented on log sheets per figure 4.

Test Duration

Approximately one (1) week. This is the time required for the cell to obtain stable operation at the defined test conditions. (1)

Special Instructions

During the initial days of conditioning, excess electrolyte will flow from the outlet air holes of the unit. This electrolyte should be drained from the cell and test fixture to prevent damage of the blower.

Acceptance Criteria

a) Voltage at 6 asf shall not exceed 1.7 volts.

b) The current (starting at 60 asf) for the last 24 hours of testing shall not drop more than 0.01 amps when operated at constant voltage.

---

(1) Stable operation is considered when the unit's voltage and current do not change significantly with time.

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

WVE # CONDITIONING
TEST ENGINEER

NAME OF RIG
D

PROJECT & ENG. ORDER NO.
NAS 9-13679

TEST PLAN NO.
MODEL NO.
PART NO.
SERIAL NO.
OPERATORS

DATE	TIME	FAN ΔP	CHAMB TEMP	TEMP OUT	D.P IN	H_2 TEMP	H_2 BACK PRESS	H_2 FLOW	N_2 DILU'T INFLOW	O_2 CONC	CURRENT	VOLTAGE	COMB GAS
		"H_2O	°F	°F	°F	°F	PSIA	SCCM	SCALE	%	ASF	VDC	SCALE
		●	●		●		●			●	●		

REMARKS:
● - SET / MAINTAINED PARAMETER

NOTE: DATA RECORDED TWICE / DAY WITH EXCEPTION OF WEEKENDS & HOLIDAYS

9656 A

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FIGURE 4 SAMPLE OF WVE CONDITIONING TEST LOG SHEETS

SECTION II

HDC CELL PAIR CONDITIONING TEST PLAN

HDC CONDITIONING

This Test Plan describes the method used to condition the HDC cell pair assembly prior to its incorporation in the One-Man E/C ARS.

Test Facilities

Reference figures 1 and 3.

Test Procedure

Each unit will be inserted into the cell pair test fixture and installed in the test chamber. Set and maintain the inlet air and unit at the conditions as outlined below. Data will be taken daily and presented on log sheets per figure 5. A

Parameter	Set Condition	
Air Flow	10 scfm	
Inlet Air Temperature	70°F	
Inlet Air Dew Point Temperature	65°F	B
Chamber P_{CO_2}	3 mmHg	
Chamber O_2 Concentration	20%	
Current Density	18 asf	
H_2 Flow	600 scc/min	
H_2 Back Pressure	1 psig	

Test Duration

Approximately three (3) weeks. This is the time required for the cell to obtain stable operation at the defined test conditions. (1) B

Special Instructions

During the initial days of conditioning, excess electrolyte will flow from the outlet air holes of the unit. This electrolyte should be drained from the cell and test fixture to prevent damage of the blower.

Performance Goals B

a) Voltage at 18 asf shall not be less than 0.200 volts after 24 hours. A

b) The voltage decay rate (at 18 asf) for the last 24 hours of testing shall not exceed 50 μ volts/hour.

---

(1) Stable operation is considered when the unit's voltage and current do not change significantly with time.

Performance Goals - Continued

c) The current CO_2 removal efficiency, for the last 24 hours of testing, at 18 asf and P_{CO_2} at 3.0 mmHg shall not be less than 71%. B

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

UA

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

HDC # CONDITIONING

TEST ENGINEER

NAME OF RIG
A-B OR C

PROJECT & ENG. ORDER NO.
NAS 9-13679

SHEET OF DATE

TEST PLAN NO.

MODEL NO.

PART NO.

SERIAL NO.

OPERATORS

DATE	TIME	FAN ΔP	CHAMB TEMP	TEMP OUT	D.P. IN	P_{CO_2} IN LIRA	H_2 FLOW	MATRIX PRESS	H_2+CO_2 FLOW	H_2 LIRA	CURRENT	VOLTAGE	POWER	CO_2 CONC.	ACT CO_2	CELL EFF	O_2 CONC	COMB GAS				
		"H_2O	°F	°F	°F	SCALE	SCALE	PSIA	SCCM	SCALE	ASF	VDC	WATTS	%	SCCM	%	%	SCALE				
		●	●		●	●	●	●			●						●					

REMARKS:
● - SET/MAINTAINED PARAMETER

NOTE: DATA RECORDED TWICE/DAY WITH EXCEPTION OF WEEKENDS & HOLIDAYS

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FIGURE 5 SAMPLE OF HDC CONDITIONING TEST LOG SHEETS

SECTION III

ONE-MAN E/C ARS TESTING

ONE-MAN E/C ARS TESTING

This Test Plan describes the tests and procedures which will be conducted on the One-Man E/C ARS for compliance with the NASA contract, NAS 9-13679 test requirements. This system consists of the SVSK 88484 One-Man E/C ARS cell pair package and SVSK 88485 One-Man E/C ARS instrumentation and control package.

Test Facility

Reference figures 1 and 2.

Test Procedure

Install the cell pair package in the test chamber. Place the instrumentation/control package adjacent to the chamber. The test sequence, set/maintained conditions, test duration and data acquisition are specified in Table II. The test durations noted in Table II are based on an estimated time for the cell pairs to obtain a stable operating condition. This time will be shortened if possible and added to the duration of the end base point test. Test data will be recorded on log sheets per figure 6.

Presentation of Data

A running plot of the unit's performance (WVE voltage, HDC voltage and CO_2 removal) vs time will be maintained throughout the test program. Other performance and parametric data will be graphically presented.

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Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION WINDSOR LOCKS, CONNECTICUT 06096 SPACE & LIFE SYSTEMS LABORATORY LOG OF TEST	TYPE OF TEST: ONE MAN E/C ARS S/N01 TEST ENGINEER: NAME OF RIG: PROJECT & ENG. ORDER NO.: NAS913679	SHEET OF DATE TEST PLAN NO. MODEL NO. PART NO. SERIAL NO. OPERATORS

DATE	ON TIME	INLET AIR CONDITIONS					AIR TEMP OUT		H_2 BACK PRESS.			HDC PERFORMANCE										WVE PERFORMANCE									
	TIME	FLOW	TEMP	D.P.	P_{CO_2}	$\%O_2$	WVE	HDC	WVE	HDC		H_2+CO_2 FLOW	CO_2 REMOV	EFF	CURR.	VOLT	V_1	V_2	V_3	V_4		CURR	VOLT	V_1	V_2	V_3	V_4	H_2 FLOW			
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI		SCCM	SCCM	%	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS		AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM			

REMARKS:

ECS-730029-L-009
REVISION A
REVISION B

A-20

9753

FIGURE 6 SAMPLE OF ONE-MAN E/C ARS TEST LOG SHEETS

TABLE II SYSTEM TEST MATRIX

Test No.	Inlet Air Conditions		HDC Current asf	Test Duration Weeks	WVE Current asf
	Dry Bulb/Dewpoint °F °F	P_{CO_2} mm Hg			
1. System Conditioning	70°/60°	3.0	18	2	50
2. System Conditioning		2.5	18	1	
3. Base Point #1		2.5	10	1	
4. Base Point #2		1.0	10	1	
5. Parametric (a)		1.0	5	1	
6. Parametric (b)		1.0	7	1	
7. Parametric (c)		1.0	14	1/2	
8. Parametric (d)		1.0	18	1/2	
9. Parametric (e)		2.5	5	1	
10. Parametric (f)		2.5	7	1	
11. Parametric (g)		2.5	14	1/2	
12. Parametric (h)		2.5	18	1/2	
13. Base Point #1		2.5	10	1/2	
14. Base Point #2	70°/60°	1.0	10	1/2	50

Air flow will be maintained at 20 scfm.
Percent of oxygen in inlet air will be maintained at 20-21%.
N_2 purging of system will be limited to occasions when voltage levels drop below system control value.

APPENDIX B TEST LOG SHEETS

HSF 175 1A 1/68

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C ARS S/N 01
TEST ENGINEER:
NAME OF RIG:
PROJECT & ENG. ORDER NO.: NAS913679

SHEET 1 OF
DATE 5/28/74
TEST PLAN NO.
MODEL NO.
PART NO.
SERIAL NO.
OPERATORS

ORIGINAL PAGE IS OF POOR QUALITY

DATE	ON TIME (HRS)	INLET AIR CONDITIONS: FLOW (SCFM)	TEMP (°F)	D.P. (°F)	P_{CO_2} (mmHg)	$\%O_2$ (%)	AIR TEMP OUT: WVE (°F)	HDC (°F)	H_2 BACK PRESS.: WVE (PSI)	HDC (PSI)	HDC PERFORMANCE: H_2+CO_2 FLOW (SCCM)	CO_2 REMOV (SCCM)	EFF (%)	CURR. (AMPS)	VOLT (TOTAL VOLT)	025 (VOLTS)	026 (VOLTS)	027 (VOLTS)	028 (VOLTS)	WVE PERFORMANCE: CURR (AMPS)	VOLT (TOTAL VOLT)	005 (VOLTS)	004 (VOLTS)	003 (VOLTS)	002 (VOLTS)	H_2 FLOW (SCCM)		SEPERATE CELL TEST DATA AT 18 AMPS: VOLTAGE (VDC)	CO_2 EFF (%)
5/28	—	20	70	63	3.0	20								18						50							START OF SYS. TEST. 0800 HRS.		
5/28	8	20	70	63	3.0	20	73	73	1.7	1.0	1260	448	83	18	1.085	.240	.310	.270	.265	50	6.56	1.642	1.638	1.660	1.620	1390	①		
5/29	18	20	70	62	3.0	21	74	73	1.7	1.0	1264	448	83	18	1.183	.240	.308	.270	.266	50	6.56	1.642	1.638	1.660	1.620	1390	①		
5/30	28	20	70	62	3.0	21	74	73	2.0	1.3	1258	448	83	18	1.220	.290	.340	.320	.290	50	6.56	1.643	1.639	1.660	1.620	1390	①		
5/31	38	20	70	62	3.0	20	75	74	2.0	1.3	1265	421	78	18	1.290	.310	.340	.320	.270	50	6.57	1.643	1.639	1.660	1.625	1390	①		
6/3	50	20	72	63	2.5	20	76	75	1.7	1.0	1260	378	70	18	1.225	.305	.335	.305	.280	50	6.56	1.693	1.692	1.635	1.635	1390	②		
6/4	74	20	72	64	2.5	20	76	75	1.7	1.0	1265	378	70	18	1.190	.280	.330	.300	.305	50	6.60	1.643	1.642	1.680	1.635	1390			
6/5	98	20	74	62	2.5	21	79	77	1.7	1.0	1260	378	70	19	1.135	.270	.305	.280	.280	50	6.59	1.620	1.662	1.665	1.645	1390			
6/6	122	20	74	25	2.5	21	79	78	1.6	1.0										50	7.37	1.90	1.780	1.920	1.770	1390	③		
6/7	146		72	48	2.5	21																					④		
6/12	170	20	73	60	2.5	20	77	76	1.8	1.0	1255	367	68	18	1.020	.285	.240	.265	.230	50	6.77	1.660	1.730	1.720	1.660	1390	⑤		
6/13	186	20	69	58	2.5	21	72	72	1.8	1.0	1250	367	68	18	1.108	.318	.250	.270	.270	50	6.78	1.665	1.730	1.705	1.660	1390			
6/14	210	20	75	65	2.5	21	79	78	1.7	1.0	1260	373	69	18	.894	.238	.226	.220	.210	50	6.83	1.680	1.745	1.725	1.670	1390			
6/15	234	20	75	56	2.5	20	79	78	1.7	1.0	1260	373	69	18	.862	.210	.224	.218	.210	50	6.84	1.690	1.740	1.725	1.680	1390			
6/17	282	20	75	30	2.5	20	79	79	1.7	1.0										50.	7.17	1.82	1.78	1.66	1.71	1390	③		
6/18	306	20	73	63	2.5	20	75	74	1.2	0.5	1255	297	55	18	.896	.207	.228	.241	.220	50	6.83	1.678	1.758	1.735	1.660	1380			
6/19	330	20	73	65	2.5	21	75	74	1.2	0.5	1255	297	55	18	.878	.205	.225	.240	.208	50	6.81	1.664	1.758	1.735	1.652	1380			
6/20	353	23	74	65	2.5	21	76	76	2.0	1.4		223	55	18		.244	.244	.280	⑥	50	6.73	1.663	1.702	1.704	1.658	1380		.295	56
6/21	376	23	75	65	2.5	20	77	77	2.0	1.4		223	55	18		.243	⑥	.282	.248	50	6.73	1.663	1.700	1.700	1.658	1380		.270	64
6/22	399	23	75	65	2.5	20	77	75	2.0	1.4		243	60	18		.262	.210	⑥	.245	50	6.73	1.660	1.700	1.702	1.658	1380		.280	65
6/23	422	23	75	65	2.5	20	77	75	2.2	1.6		235	58	18		⑥	.211	.265	.208	50	6.73	1.664	1.701	1.702	1.650	1380		.260	50

REMARKS:

① SYS. SHUT DOWN OVERNIGHT (NOT ATTENDED)

② STARTED SYS. UP AT 2000 HRS 6/2

③ VERY LOW R.H. HDC CURRENT CONTROL NOT MAINTAINED. WVE'S HELD AT 50 AMPS, VOLTAGES WENT UP. STARTED REWETTING CELLS.

④ H_2 LEAKAGE IN WVE'S - S/N 003 REMOVED AND ITS CENTER HSG REPLATED. RESTART OF SYS. TEST 0800 HRS 6/11

⑤ FACILITY POWER LOSS - SYS. DOWN FOR 8 HRS.

⑥ HDC CELL (AS INDICATED) REMOVED FROM SYS. AFTER PREVIOUS DAY READINGS AND PLACED ON SEPERATE TEST. SYS. DOWN 1 HR ON EACH REMOVAL.

HSP 175 1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

UA

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C ARS S/No1

TEST ENGINEER:

NAME OF RIG:

PROJECT & ENG. ORDER NO.: NAS913679

SHEET 2 OF

DATE:

TEST PLAN NO:

MODEL NO:

PART NO:

SERIAL NO:

OPERATORS:

DATE	ON TIME	INLET AIR CONDITIONS					AIR TEMP OUT		H_2 BACK PRESS.	
		FLOW	TEMP	D.P.	P_{CO_2}	$\%O_2$	WVE	HDC	WVE	HDC
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI
6/24	446	24	75	65	2.5	21	78	77	2.2	1.6
6/25	470	20	75	65	2.5	21	78	76	1.7	1.0
6/26	494	20	66	62	2.5	20	70	70	1.7	1.0
6/27	518	20	65	62	2.5	20	69	69	1.7	1.0
6/28	542		65	62	2.5					
7/1	550	20	67	61	2.5	20	70	70	1.3	.5
7/2	566	20	71	62	2.5	21	72	72	1.3	.5
7/3	590	20	72	62	2.5	21	75	74	1.7	1.0
7/8	710	20	72	63	2.5	21	75	75	1.7	1.0
7/9	733	23	72	63	2.5	21	76	75	1.8	1.2
7/10	757	23	70	63	2.5	20	74	73	1.8	1.2
7/11	781	23	70	62	2.5	20	74	72	2.0	1.5
7/12	805	23	70	62	2.5	21	74	72	2.0	1.5
7/15	877	23	70	62	2.5	21	74	72	1.8	1.2
7/16	901	23	70	62	2.5	21	74	72	1.8	1.2

DATE	ON TIME	HDC PERFORMANCE								
		H_2+CO_2 FLOW	CO_2 REMOV	EFF	CURR.	VOLT	025	026	027	028
	HRS	SCCM	SCCM	%	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS
6/24	446		231	57	18		(6)	.195	.260	.200
6/25	470	1260	292	54	18	.983	.296	.219	.265	.203
6/26	494	1255	286	53	18	.823	.256	.180	.250	.137
6/27	518	1260	205	38	18	1.140	.289	.320	.303	.228
6/28	542									
7/1	550	1255	216	40	18	.750	.200	.256	.200	.094
7/2	566	1260	227	42	18	.876	.214	.212	.237	.213
7/3	590	1260	232	43	18	.563	.092	.174	.180	.17
7/8	710	1255	227	42	18	.540	.035	.125	.190	.190
7/9	733		194	48	18		(6)	.120	.178	.148
7/10	757		194	48	18			.115	.178	.145
7/11	781		186	46	18			.105	.175	.145
7/12	805		198	49	18			.098	.170	.140
7/15	877		203	50	18			.086	.160	.125
7/16	901		194	48	18		↓	.080	.160	.120

DATE	ON TIME	WVE PERFORMANCE							SEPARATE CELL TEST	
		CURR	VOLT	005	004	003	002	H_2 FLOW		
	HRS	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM	VOC	%
6/24	446	50.	6.75	1.665	1.701	1.702	1.684	1380	.250	50
6/25	470	50	6.72	1.660	1.702	1.706	1.648	1390		
6/26	494	50	6.72	1.660	1.700	1.701	1.650	1390		
6/27	518	50	6.72	1.680	1.690	1.700	1.650	1380		
6/28	542							(7)		
7/1	550	50	6.74	1.660	1.700	1.720	1.660	1390		
7/2	566	50	6.74	1.680	1.690	1.710	1.660	1390		
7/3	590	50.	6.74	1.680	1.70	1.710	1.66	1380		
7/8	710	50.	6.77	1.680	1.710	1.720	1.66	1380		
7/9	733	50	6.74	1.660	1.710	1.700	1.670	1380		
7/10	757	50	6.77	1.680	1.710	1.720	1.660	1380		
7/11	781	50	6.78	1.685	1.710	1.722	1.665	1380		
7/12	805	50	6.78	1.685	1.705	1.720	1.670	1380		
7/15	877	50	6.79	1.690	1.705	1.723	1.670	1380		
7/16	901	50	6.78	1.690	1.710	1.724	1.660	1380		

7/16 SYSTEM DOWN - REMOVED ALL HDC CELLS FOR DISASSEMBLY & INVESTIGATION.

901 TO 966 - RECHECK OUT of SYSTEM/RIG - JANUARY 1975

REMARKS

(7) H_2 LEAKAGE - SYS. DOWN - WVE SEAL LEAKAGE CAUSED BY CORRODED CELL NUTS. REPLACED NUTS WITH TITANIUM NUTS RESTART OF SYS. 7/1/74

B-2

ORIGINAL PAGE IS OF POOR QUALITY

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C ARS S/N01
TEST ENGINEER:
NAME OF RIG:
PROJECT & ENG. ORDER NO.: NAS9-13679

SHEET 3 OF
DATE:
TEST PLAN NO.:
MODEL NO.:
PART NO.:
SERIAL NO.:
OPERATORS:

DATE	ON TIME	INLET AIR CONDITIONS					AIR TEMP OUT		H2 BACK PRESS.		HDC PERFORMANCE									WVE PERFORMANCE							
		FLOW	TEMP	D.P.	P_{CO_2}	%O_2	WVE	HDC	WVE	HDC	H_2+CO_2 FLOW	CO_2 REMOV	EFF	CURR.	VOLT	029	030	031	032	CURR	VOLT	V_1^{005}	V_2^{004}	V_3^{003}	V_4^{002}	H_2 FLOW	
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI	SCCM	SCCM	%	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM	
1/9/75	964	20	68	61	3.0	20			1.2	.4				18						50	6.80	1.72	1.70	1.72	1.66	1380	①
1/10	986	20	67	61	5.0	20	70	70	1.2	.4	1350	400	74	18	.624	.189	.190	.110	.185	50	6.83	1.722	1.717	1.728	1.66	1380	
1/13	1058	20	68	62	3.0	21	72	72	1.7	1.0	1360	400	74	18	.517	.190	.113	.110	.104	50	6.84	1.725	1.720	1.730	1.665	1380	
1/14	1082	20	68	62	3.0	20	72	72	1.7	1.0	1355	405	75	18	.496	.210	.113	.109	.064	50	6.85	1.725	1.720	1.730	1.670	1380	② P
1/15	1106	20	90	60	3.0	20	96	94	1.7	1.0	-	-	-	14	.366	.060	.060	.116	.130	50	7.04	1.72	1.77	1.78	1.77	1380	③
	1113	20	73	60	3.0	21	76	76	1.3	.5	1355	405	75	18	.495	.103	.087	.105	.150	50	6.84	1.732	1.715	1.724	1.67	1380	
1/16	1130	20	73	60	5.0	21	76	76	1.3	.5	1252	400	74	18	.417	.077	.104	.106	.130	50	6.86	1.734	1.720	1.730	1.672	1380	
1/17	1154	20	74	60	5.0	20	75	75	1.3	.5	1355	400	74	18	.427	.086	.105	.108	.128	50	6.85	1.731	1.72	1.728	1.672	1380	
1/20	1226	20	68	62	3.0	20	72	72.5	1.3	.5	1360	383	71	18	.378	.064	.103	.106	.105	50	6.84	1.725	1.720	1.722	1.670	1380	
1/21	1250	20	68	62	3.0	20	73.	73.	1.3	.5	1354	394	73	18	.372	.064	.101	.102	.105	50	6.83	1.720	1.718	1.720	1.670	1380	
1/22	1274	20	68	62	2.5	20	73	72	1.5	.7	1361	394	73	18	.361	.060	.100	.100	.101	50.	6.80	1.700	1.714	1.718	1.672	1380	④ P
1/23	1298	20	68	62	2.5	20	74	73	1.4	.6	1355	394	73	18	.552	.169	.065	.098	.000	50	6.80	1.702	1.710	1.713	1.610	1380	⑤ P
1/24	1322	20	68	62	2.5	20	74	73	1.3	.5	1263	400	74	18	.563	.065	.100	.100	.098	50	6.80	1.700	1.712	1.714	1.670	1380	⑥
1/27	1394	20	75	60	2.5	20	75	74	1.5	.5	1428	378	84.	15	.324	.060	.088	.090	.086	50	6.85	1.710	1.730	1.733	1.68	1380	
1/28	1418	20	75	58	2.5	20	77	76	1.3	.5	1260	405	75	18	.437	.112	.130	.095	.100	50	6.86	1.714	1.724	1.736	1.684	1380	
1/29	1442	20	70	60	2.5	20	75	74	1.3	.5	1255	405	75	18	.320	.055	.084	.092	.086	50	6.88	1.702	1.702	1.716	1.675	1380	
1/30	1466	20	70	60	2.5	20	74	73	1.3	.5	1442	420	87.5	16	.420	.094	.122	.102	.102	50	6.79	1.702	1.701	1.720	1.670	1380	
1/31	1490	20	71	59	2.5	20	75	74	1.3	.5	1455	362	86.2	14	.542	.233	.211	.189	.209	50	6.79	1.702	1.701	1.715	1.674	1380	
2/3/75	1562	20	72	59	2.5	20	75	74	1.3	.5	1460	363	86.4	14.	.372	.093	.102	.083	.094	50	6.80	1.703	1.702	1.717	1.674	1380	
2/4/75	1586	20	70	60	1.0	20	73	70	1.2	.5	1488	55.8	38.	5.	1.764	.493	.408	.409	.456	50	6.82	1.702	1.718	1.725	1.676	1380	
2/5/75	1610	20	70	60	1.0	20	73	70	1.2	.5	1407	57.0	38	5.	1.877	.530	.431	.440	.416	50	6.81	1.700	1.715	1.721	1.675	1380	⑪ S

REMARKS:

RACK POSITION OF CELL PAIRS AT START;

HDC - 029 - V_4 WVE 002 - V_4 (TOP)
030 - V_3 003 - V_3
031 - V_2 004 - V_2
032 - V_1 (BOTTOM LAST TO GET H_2)   005 - V_1

1) RESTART OF SYSTEM TESTING
2) 1200 HRS SWITCHED POSITIONS OF 029 & 032 CELL PAIRS.
3) RIG COOLANT UNIT FAILURE ALLOWED AMB. TEMP TO INCREASE
4) REVERSED H_2 FLOW THRU HDC CELL PAIRS.
5) REVERSED H_2 FLOW BACK TO ORIGINAL POSITION
6) CHANGED TO 75/60 AT NOON.
7) CHANGED TO 10 ASF & 2.5 mmHg AFTER READING. (BASE PT.)
8) CHANGED TO 10 ASF & 1.0 mmHg AFTER READING (BASE PT #2)
9) CHANGED DEW POINT WENTORY (???)
10) CHANGED TO 5 ASF (AFTER READING)
11) CHANGED TO 7 ASF

P - 10 min Purge   S - 10 sec SHUT-OFF

B-3

HSF 178 1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C ARS S/NO1

TEST ENGINEER:

NAME OF RIG:

PROJECT & ENG ORDER NO: NAS9136'79

SHEET 4 OF DATE

TEST PLAN NO.

MODEL NO.

PART NO.

SERIAL NO.

OPERATORS

DATE	ON TIME	INLET AIR CONDITIONS					AIR TEMP OUT		H₂ BACK PRESS.	
		FLOW	TEMP	D.P.	P_{CO_2}	$\%O_2$	WVE	HDC	WVE	HDC
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI
2/6	1634	20	70	60	2.5	21	73	71	1.2	.5
2/7	1658	20	78	58	2.5	21	74	72	1.3	.5
2/8	1682	20	71	60	2.5	21	74	72	1.3	.5
2/10	1730	20	72	60	2.5	21	74	73	1.3	.5
2/11	1754	20	72	60	2.5	21	74	73	1.3	.5
2/12	1778	20	72	60	2.5	20	74	73	1.3	.5
2/13	1802	20	70	60	1.0	20	74	72	1.3	.5
2/14	1826	20	70	60	1.0	21	74	72	1.3	.5
2/17	1898	20	70	60	1.0	20	74	72	1.3	.5
2/18	1922	20	72	40	1.0	20	76	75	1.3	.5
2/19	1946	20	71	60	1.0	21	76	74	1.3	.5
2/20	1970	20	71	60	1.0	21	76	74	1.3	.5
2/21	1994	20	70	60	1.0	20	74	71	1.3	.5
2/22	2018	20	69	60	1.0	20	73	71	1.3	.5
2/24	2066	20	69	60	1.0	21	73	71	1.3	.5
2/25	2090	20	70	60	1.0	20	73	71	1.3	.5
2/26	2114	20	71	60	1.0	21	74	71	1.3	.5
2/27	2138	20	71	60	1.0	21	74	71	1.3	.5
2/28	2162	20	70	60	1.0	21	75	73	1.3	.5
3/3	2234	20	76	60	1.0	21	81	78	1.3	.5
3/4	2258	20	71	60	1.0	20	75	73	1.3	.5

DATE	HDC PERFORMANCE									WVE PERFORMANCE							
	H_2+CO_2 FLOW	CO_2 REMOV	EFF	CURR.	VOLT	029	030	031	032	CURR	VOLT	005	004	003	002	H_2 FLOW	
	SCCM	SCCM	%	AMPS	TOTAL VOLT.	VOLTS	VOLTS	VOLTS	VOLTS	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM	
2/6	1917	219	73.	10	.967	.286	.211	.206	.264	50.	6.82	1.701	1.719	1.725	1.674	1380	
2/7	1416	219.	73.	10	.853	.257	.178	.179	.239	50	6.82	1.701	1.720	1.726	1.675	1380	
2/8	1415	219	73.	10	.855	.258	.180	.180	.237	50	6.82	1.700	1.720	1.725	1.675	1380	
2/10	1424	225.	75.	10	.786	.242	.164	.163	.217	50	6.82	1.700	1.719	1.725	1.676	1380	
2/11	1435	232.	77.	10	.765	.237	.160	.159	.209	50	6.82	1.701	1.720	1.726	1.677	1380	
2/12	1439	232	77.	10	.791	.240	.169	.168	.214	50	6.82	1.701	1.720	1.727	1.677	1380	8 V
2/13	1380	158	53.	10	.861	.261	.182	.178	.240	50	6.82	1.701	1.717	1.725	1.676	1380	
2/14	1380	176	58.5	10	.795	.240	.165	.175	.215	50	6.82	1.701	1.718	1.725	1.677	1380	
2/17	1385	180	60.	10	.858	.246	.187	.197	.228	50	6.82	1.701	1.718	1.725	1.677	1380	
2/18	–	–	–	10	.382	.126	.066	.072	.118	50	6.90	1.72	1.73	1.75	1.70	1380	9
2/19	1400	194	64.7	10	.849	.235	.184	.200	.230	50	6.80	1.700	1.718	1.728	1.674	1380	
2/20	1400	190	63.3	10.	.840	.230	.186	.199	.225	50	6.80	1.698	1.710	1.718	1.674	1380	10
2/21	1409	60.	40.	5.	1.89	.509	.449	.454	.480	50	6.78	1.692	1.706	1.714	1.673	1380	
2/22	1410.	60.	40.	5.	1.84	.503	.434	.436	.467	50	6.78	1.691	1.706	1.719	1.673	1380	
2/24	1418	64.	43.	5.	1.72	.479	.404	.398	.434	50	6.79	1.694	1.707	1.714	1.674	1380	
2/25	1420	66.	44.	5	1.66	.471	.387	.378	.422	50	6.79	1.693	1.708	1.715	1.674	1380	
2/26	1422	66	44.	5	1.67	.476	.389	.377	.426	50	6.79	1.695	1.708	1.715	1.674	1380	
2/27	1420	66	44.	5	1.66	.475	.384	.371	.425	50	6.79	1.695	1.708	1.715	1.674	1380	11 V
2/28	1410	114.	54.	7	1.34	.372	.319	.309	.337	50	6.79	1.694	1.707	1.714	1.674	1380	
3/3	1440	149.	70.7	7	.977	.304	.214	.203	.256	50	6.84	1.706	1.720	1.735	1.682	1380	
3/4	1440	126	60.	7	1.27	.360	.291	.296	.326	50	6.82	1.700	1.713	1.725	1.677	1380	

REMARKS:

B-4

ORIGINAL PAGE IS OF POOR QUALITY

HSF 175 1A 1/66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

WINDSOR LOCKS, CONNECTICUT 06096

UA

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST	ONE MAN E/C ARS S/N01
TEST ENGINEER	
NAME OF RIG	
PROJECT & ENG. ORDER NO.	NAS913679
SHEET	5 OF
DATE	
TEST PLAN NO.	
MODEL NO.	
PART NO.	
SERIAL NO.	
OPERATORS	

DATE	ON TIME	INLET AIR CONDITIONS					AIR TEMP OUT		H2 BACK PRESS.	
		FLOW	TEMP	D.P.	P_{CO_2}	$\%O_2$	WVE	HDC	WVE	HDC
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI
3/5	2282	20	70	60	1.0	21	74	72	1.3	.5
3/6	2306	20	71	60	1.0	21	74	72	1.3	.5
3/7	2330	20	71	60	1.0	20	75	74	1.3	.5
3/8	2354	20	71	60	1.0	20	75	74	1.3	.5
3/10	2402	20	71	60	1.0	21	75	74	1.3	.5
3/11	2426	20	71	60	1.0	21	75	74	1.3	.5
3/12	2450	20	71	60	1.0	21	75	74	1.3	.5
3/13	2474	20	73	60	1.0	20	76	74	1.3	.5
3/14	2498	20	71	60	2.5	20	75	74	1.3	.5
3/15	2522	20	71	60	2.5	20	75	74	1.3	.5
3/17	2570	20	72	60	2.5	20	75	74	1.3	.5
3/18	2594	20	71	60	2.5	20	75	74	1.3	.5
3/19	2618	20	74	60	2.5	20	78	76	1.3	.5
3/20	2642	20	72	60	2.5	20	76	74	1.3	.5
3/21	2666	20	72	60	2.5	20	76	74	1.3	.5
3/22	2690	20	72	60	2.5	21	76	73	1.3	.5
3/24	2738	20	72	60	2.5	21	76	73	1.3	.5
3/25	2762	20	72	60	2.5	21	76	73	1.3	.5
3/26	2786	20	72	59	2.5	20	76	74	1.3	.5
3/27	2810	20	72	59	2.5	20	76	73	1.3	.5
3/27	2816	20	72	59	2.5	20	75	72	1.0	.2

DATE	HDC PERFORMANCE								
	H_2+CO_2 FLOW	CO_2 REMOV	EFF	CURR.	VOLT	029	030	031	032
	SCCM	SCCM	%	AMPS	TOTAL VOLT.	VOLTS	VOLTS	VOLTS	VOLTS
3/5	1444	126	60.	7	1.26	.358	.290	.292	.324
3/6	1470	126	60.	7	1.25	.350	.283	.290	.324
3/7	1320	203	48.9	14	.35	.120	.068	.085	.080
3/8	1310	214	51.	14	.33	.108	.060	.082	.018
3/10	1305	220	52.3	14	.33	.091	.072	.091	.081
3/11	1220	231	43.0	18	.28	.088	.058	.067	.060
3/12	1250	221	46.	16	.30	.115	.039	.101	.048
3/13	1240	221	46	16	.296	.109	.042	.100	.045
3/14	1400	365	76	16	.32	.090	.068	.091	.072
3/15	1430	331	78.8	14	.53	.116	.116	.146	.151
3/17	1410	331	78.8	14	.42	.094	.088	.128	.109
3/18	1420	340	81.	14	.35	.085	.069	.106	.090
3/19	1415	340	81.	14	.35	.084	.070	.108	.092
3/20	1460	146	69.6	7	1.50	.405	.346	.358	.390
3/21	1465	152	72.5	7	1.44	.388	.332	.350	.366
3/22	1470	159	73.1	7	1.41	.384	.328	.342	.358
3/24	1460	154	73.1	7	1.38	.377	.320	.336	.348
3/25	1450	156	74.3	7	1.34	.367	.312	.326	.335
3/26	1445	156	74.3	7	1.34	.367	.312	.324	.333
3/27	1450	100	66.6	5	1.86	.500	.442	.444	.475
3/27	1450	100	66.6	5	1.84	.495	.435	.435	.470

DATE	WVE PERFORMANCE							
	CURR	VOLT	005	004	003	002	H_2 FLOW	
	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM	
3/5	50	6.78	1.691	1.703	1.713	1.671	1380	
3/6	50	6.80	1.695	1.709	1.719	1.675	1380	(11)
3/7	50	6.81	1.698	1.712	1.722	1.676	1380	
3/8	50	6.81	1.697	1.710	1.723	1.677	1380	
3/10	50	6.80	1.698	1.710	1.720	1.676	1380	(12)
3/11	50	6.80	1.698	1.710	1.721	1.676	1380	
3/12	50	6.80	1.697	1.711	1.722	1.674	1380	
3/13	50	6.81	1.700	1.713	1.723	1.677	1380	
3/14	50	6.82	1.704	1.716	1.726	1.678	1380	
3/15	50	6.81	1.700	1.711	1.721	1.675	1380	
3/17	50	6.81	1.704	1.710	1.720	1.675	1380	
3/18	50	6.83	1.710	1.715	1.726	1.678	1380	
3/19	50	6.82	1.709	1.714	1.725	1.677	1380	
3/20	50	6.82	1.710	1.719	1.725	1.677	1380	
3/21	50	6.83	1.710	1.715	1.727	1.677	1380	
3/22	50	6.82	1.708	1.713	1.725	1.677	1380	
3/24	50	6.83	1.710	1.715	1.727	1.679	1380	
3/25	50	6.83	1.711	1.715	1.727	1.679	1380	
3/26	50	6.83	1.711	1.715	1.729	1.680	1380	
3/27	50	6.84	1.711	1.717	1.730	1.680	1380	
3/27	20	6.35	1.580	1.590	1.600	1.580		(14)

REMARKS:

(11) INCREASED HDC CURRENT TO 14 AMPS AFTER READING

(12) INCREASED HDC CURRENT TO 18 AMPS, AFTER READING

(14) PLANT FACILITY CHILLED WATER OFF REDUCED WVE TO 20 AMPS TO REDUCE HEAT LOAD ON TEST CHAMBER COOLANT UNIT. RETURNED TO 50 AMPS 3/31/75

HSF 176 1A 1-66

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C AES S/N 01

TEST ENGINEER:

NAME OF RIG:

PROJECT & ENG. ORDER NO: NAS9-13679

SHEET 6 OF ____ DATE ____

TEST PLAN NO:

MODEL NO:

PART NO:

SERIAL NO.

OPERATORS:

DATE	ON TIME HRS	INLET AIR CONDITIONS FLOW SCFM	TEMP °F	D.P. °F	P_{CO_2} mmHg	$\%O_2$ %	AIR TEMP OUT WVE °F	HDC °F	H_2 BACK PRESS. WVE PSI	HDC PSI
3/28	2834	20	73	59	2.5	20	74	79	1.0	.2
3/29	2858	20	73	60	2.5	20	74	73	1.0	.2
5/31	2906	20	72	59	2.5	20	74	73	1.0	.2
3/31	2908	20	72	59	2.5	20	76	73	1.3	.5
4/1	2932	20	70	60	2.5	20	75	73	1.3	.5
4/2	2956	20	71	60	2.5	20	75	73	1.3	.5
4/3	2980	20	71	59	2.5	21	75	73	1.3	.5
4/4	3004	20	73	58	2.5	21	76	74	1.3	.5
4/5	3028	20	74	58	2.5	21	77	75	1.3	.5
4/7	3076	20	74	58	1.0	21	77	75	1.3	.5
4/8	3100	20	73	58	1.0	20	76	74	1.3	.5
4/9	3124	20	72	60	1.0	20	75	74	1.3	.5
4/10	3148	20	71	58	3.0	20	75	73	1.3	.5
4/11	3172	20	72	59	3.0	20	76	74	1.3	.5
4/12	3196	20	72	59	3.0	20	77	75	1.3	.5
4/14	3244	20	70	60	3.0	20	74	71	1.3	.5
4/15	3268	20	72	59	3.0	21	76	73	1.3	.5
4/16	3292	20	70	60	3.0	20	75	73	1.3	.5
4/17	3316	20	72	59	3.0	20	76	74	1.3	.5
4/18	3340	20	73	59	3.0	21	77	75	1.3	.5
4/19	3364	20	112	68	3.0	21	115	112	1.3	.5

DATE	HDC PERFORMANCE H_2+CO_2 FLOW SCCM	CO_2 REMOV SCCM	EFF %	CURR. AMPS	VOLT TOTAL VOLT	029 VOLTS	030 VOLTS	031 VOLTS	032 VOLTS
3/28	530	90	60.	5	1.67	.437	.396	.399	.440
3/29	520	90	60.	5	1.63	.425	.386	.392	.428
5/31	590	98	65	5	1.54	.405	.366	.368	.402
3/31	1440	108	72	5	1.68	.453	.395	.407	.425
4/1	1450	110	73.4	5	1.68	.467	.390	.400	.427
4/2	1495	109	72.7	5	1.66	.460	.386	.395	.424
4/3	1460	240	80.	10	.914	.250	.205	.221	.238
4/4	1465	240	80	10	.840	.228	.186	.211	.215
4/5	1450	240	80	10	.824	.221	.182	.211	.212
4/7	1390	202	67.3	10	.948	.250	.228	.230	.240
4/8	1410	210	70.	10	.856	.220	.212	.216	.208
4/9	1425	219	73	10	.829	.212	.200	.212	.205
4/10	1460	258	86.	10	.948	.240	.212	.243	.253
4/11	1455	252	84	10	.926	.232	.206	.240	.248
4/12	1460	265	88	10	.900	.220	.198	.232	.240
4/14	1450	111	74	5	1.72	.470	.413	.427	.457
4/15	1470	117	78	5	1.69	.450	.400	.406	.432
4/16	1440	361	86	14	.498	.117	.095	.123	.123
4/17	1495	377	89.7	14	.399	.097	.096	.108	.098
4/18	1470	380	90.5	14	.326	.084	.080	.082	.080
4/19				18					

DATE	WVE PERFORMANCE CURR AMPS	VOLT TOTAL VOLT	005 VOLTS	004 VOLTS	003 VOLTS	002 VOLTS	H_2 FLOW SCCM	
3/28	20	6.37	1.583	1.590	1.608	1.588	500	
3/29	20	6.57	1.584	1.591	1.609	1.588	500	
5/31	20	6.37	1.584	1.592	1.609	1.589	500	
3/31	50	6.80	1.703	1.703	1.719	1.675	1380	
4/1	50	6.82	1.708	1.708	1.723	1.676	1380	
4/2	50	6.83	1.711	1.711	1.726	1.678	1380	
4/3	50	6.83	1.711	1.712	1.727	1.678	1380	
4/4	50	6.84	1.719	1.714	1.730	1.679	1380	
4/5	50	6.84	1.714	1.716	1.732	1.680	1380	
4/7	50	6.89	1.719	1.716	1.743	1.681	1380	
4/8	50	6.85	1.716	1.718	1.735	1.683	1380	
4/9	50	6.84	1.715	1.717	1.733	1.682	1380	
4/10	50	6.85	1.716	1.717	1.733	1.683		
4/11	50	6.85	1.717	1.719	1.734	1.683		
4/12	50	6.84	1.716	1.716	1.732	1.691		
4/14	50	6.85	1.717	1.717	1.731	1.683		
4/15	50	6.86	1.720	1.720	1.735	1.684		
4/16	50	6.87	1.724	1.722	1.736	1.685		
4/17	50	6.87	1.725	1.723	1.736	1.686		
4/18	50	6.87	1.725	1.724	1.738	1.686		15
4/19	50	7.08	1.768	1.786	1.810	1.717		16

REMARKS:

15 4/18/75 - ONTIME 3343 SYSTEM OPERATED AT 18 AMPS (HDC) WITH ONE HR ON & 5 SEC OFF BUT MAINTAINED 18 AMPS AT ALL TIME.

16 4/19/75 - RIG COOLANT UNIT MALFUNCTIONED ALLOWING TEMP. TO RISE. NOTE NO H_2 CROSS OVER. HDC POWER TOO LOW TO CONTROL. SHUT SYSTEM DOWN UNTIL MONDAY 4/21/75 AT 1030 HRS.

Hamilton Standard
WINDSOR LOCKS, CONNECTICUT 06096

SPACE & LIFE SYSTEMS LABORATORY

LOG OF TEST

TYPE OF TEST: ONE MAN E/C ARS S/NO1

TEST ENGINEER:

NAME OF RIG:

PROJECT & ENG ORDER NO: NAS9-13679

SHEET 7 OF

DATE:

TEST PLAN NO:

MODEL NO:

PART NO:

SERIAL NO:

OPERATORS:

DATE	ON TIME	INLET AIR CONDITIONS FLOW	TEMP	D.P.	P_{CO_2}	$\%O_2$	AIR TEMP OUT WVE	HDC	H_2 BACK PRESS. WVE	HDC
	HRS	SCFM	°F	°F	mmHg	%	°F	°F	PSI	PSI
4/21	3369	20	70	60	3.0	21	74	73	1.3	.5
4/22	3385	20	70	60	5.0	21	74	73	1.3	.5
4/23	3409	20	70	58	3.0	20	73	72	1.3	.5
4/24	3433	20	70	59	3.0	20	75	74	1.3	.5
4/25	3457	20	70	59	3.0	20	75	74	1.3	.5
4/28	3529	20	70	60	3.0	20	75	74	1.3	.5
4/29	3553	20	70	59	3.0	20	74	72	1.3	.5
4/30	3577	20	70	59	3.0	20	74	72	1.3	.5

DATE	HDC PERFORMANCE H_2 FLOW	CO_2 REMOV.	EFF	CURR.	VOLT					WVE PERFORMANCE CURR	VOLT					H_2 FLOW
	SCCM	SCCM	%	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	AMPS	TOTAL VOLT	VOLTS	VOLTS	VOLTS	VOLTS	SCCM
4/21	1365	389	72.	18	.660	.200	.171	.183	.106	50	6.92	1.725	1.741	1.765	1.693	
4/22	1360	399	73.9	18	.619	.165	.168	.184	.102	50	6.88	1.720	1.726	1.748	1.687	
4/23	1365	400	74.	18	.448	.122	.146	.130	.050	50	6.89	1.726	1.730	1.752	1.690	
4/24	1370	402	74.3	18	.456	.110	.138	.148	.060	50	6.90	1.730	1.733	1.756	1.691	
4/25	1370	400	74.	18	.442	.110	.130	.147	.055	50	6.91	1.730	1.734	1.754	1.690	
4/28	1375	397	73.5	18	.443	.100	.133	.145	.065	50	6.89	1.727	1.730	1.747	1.688	
4/29	1370	400	74.	18	.445	.105	.135	.143	.062	50	6.89	1.727	1.731	1.746	1.689	
4/30	1360	397	73.5	18	[illegible]	.100	.133	.146	.064	50	6.88	1.725	1.730	1.744	1.688	

SYSTEM SHUT DOWN - START REFURBISHMENT FOR SHIPMENT

REMARKS

9753